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ELEMENTS OF ANATOMY AND PHYSIOLOGY FOR NURSES

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ELEMENTS

OF

ANATOMY AND PHYSIOLOGY

FOR

NURSES

BY

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1917

To

MARY ADELAIDE NUTTING

WHOSE INSIGHT AND ENTHUSIASM FIRST AROUSED MY
ENDURING INTEREST IN THE EDUCATIONAL
PROBLEMS OF THE TRAINING SCHOOL
THIS BOOK IS CORDIALLY
DEDICATED

43251

PREFACE

In the composition of this book the writer has been guided by his own needs and influenced by the following reflections. The field of Anatomy and Physiology is too large to be treated adequately in a textbook of less than several volumes. No nurse can or need become acquainted with the whole field, but she should know pretty well those parts which border on her own experience. The training school may then with propriety seek to make the nurse thoroughly familiar with a very few fundamental and typical phenomena such as may be presented in a little book, and furthermore it should encourage her to work up her cases from the larger reference books — just as the doctor does, although of course in much less detail and from a somewhat different standpoint. If she has thoroughly grasped the rudiments of the subject, this procedure will be an easy and pleasant one. This is no new-fangled notion, for the "case method" of teaching law and medical students is an old story. The case method has among other advantages this very obvious one, that the facts acquired in this way are a much more permanent acquisition than is the case when they are served cold, so to speak, in a lesson book.

In accordance with this line of thought, the writer has endeavored to explain with great care, and in terms of chemistry and physics, a few important physiological processes, and to picture a few salient anatomical features. Such a book as the present one demands judgment in selection of material and lucidity in its presentation. It is left to the reader to decide in how far this demand has been met.

Although the desire of the writer has been to make the book a small one, it has seemed equally advisable to avoid any condensations which might lead to obscurity. Consequently he has not spared words, nor shrunk from repetitions and has availed himself of numerous homely illustrations, which had already proved their usefulness as blackboard drawings.

The original drawings, seventy-four in number, have been supplemented by illustrations carefully selected from other books, some of which, in accordance with an agreement with the publishers, are listed as follows: —

Figures 31–35, 37, 74, 81, 83, 84, 88, 90, 99, 100, 106, 114–116, 122, 123, 135, 140 B, are from Howell's Physiology, W. B. Saunders Company.

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Figures 52, 54, 55, from Holden's Anatomy, P. Blakiston's Son and Company.

Figures 38, 58, 59, 75, 80 B, from Kimber's Anatomy and Physiology for Nurses, The Macmillan Company.

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Anatomy, Lea, Febiger and Company; Dunham's Histology, Lea, Febiger and Company; Dorland's Obstetrics, W. B. Saunders Company; Huxley's Physiology, The Macmillan Company.

Besides these, mention should be made of Fig. 124, 138 A, 142 B, from original articles by Miller, Langley, and Mall, respectively; 121 B, from Harvey; 153, 154, from Henle; 152, from H. Frey; 11, 61, from Spalteholtz; 80 A, 98, from Toldt.

Those who have labored in such a scholarly and rational manner for the amelioration of English spelling may question the sincerity of the writer's sympathy with the Simplified Spelling movement. The writer desires to assure these persons that only with the greatest reluctance has he yielded to the demand of his publisher that the book be printed in the conventional mode.

In closing I wish to express my heartiest appreciation of the kindness of Professor J. R. Murlin, of Cornell, for reading and criticizing my manuscript for me; of Professor William S. Miller, of Wisconsin, for his valuable suggestions in regard to anatomical illustrations; of Mrs. Benjamin H. Schlomovitz, of Iowa City, for clerical service freely and abundantly given; and of Mr. Noel G. Monroe for his partial revision of the anatomical nomenclature.

UNIVERSITY OF WISCONSIN.

A FEW SUGGESTIONS TO TEACHERS AND PUPILS

It has been my experience that teachers, especially those upon whom the duty of instructing nurses has fallen almost without warning, are glad to listen to suggestions from any sympathetic source. I shall therefore devote a few paragraphs to the teacher, while the pupil, in so far as she is the teacher of herself, may also listen with profit.

The Dictionary. All through her course, and also later, the nurse will be continually meeting with unfamiliar words. For these she will turn to her medical dictionary if she has acquired the *habit* of so doing. This habit cannot be acquired too soon, and its formation is only delayed by giving her access to a few excerpts from the dictionary under the title of a "glossary." The practice of never letting an obscure word go by is to be commended.

The Summary. Among the most excellent of pedagogic devices is that of requiring the pupil to summarize the textbook chapter by chapter. The pupil may also be required, or at any rate encouraged, to take each paragraph and ask herself, What does it mean? What evidence is there that it is true? Of what importance is it anyway? The answers to these questions are only partly contained in the text and the pupil should learn to keep a sharp lookout that she may be able to recognize the remaining answers when she meets them, whether this be in her more advanced studies, in the pages of a journal, in her experience in the ward or anywhere else. The value of this procedure lies largely in the impressiveness of the number of unanswered questions. There is nothing so detrimental to intellectual vigor as a textbook which undertakes to tell the pupil everything she ought to know. In my own classes I would have it known that textbooks are incomplete and instructors not fully informed, and that if the pupil is to amount to anything intellectually she must find out a great many things for herself through observation, experience, and abundant reading.

Anatomy. One of the reasons why the "dark ages" were so dark was the prevalence of the belief that anatomy could be learned by the perusal of ancient descriptions. The Renaissance substituted for the written word of the savant the human cadaver. This hastened the change in men's attitude towards anatomy and indeed toward all medical science. From that time it has been realized that anatomy can only be adequately taught when there is careful dissection. To-day, whenever dissection is inexpedient or temporarily impossible, we note it with regret, and we try to find some substitute which shall be at least partially adequate. It is safe to say that at the present time the vast majority of training schools for nurses do not require dissection either for admission or during the period of probation, but are seeking for some such temporary substitute as has been referred to. In this connection I offer the following suggestions.

1. Material such as eyes, hearts, lungs, and other viscera can be obtained at small cost at the slaughter house, and will, if dissected, give the pupil considerable familiarity with these viscera.
2. If a projection lantern is available it can be used to familiarize the pupils with the general appearance and especially with the relations of the organs. It is advantageous for the teacher to throw a picture on the screen and then to question the pupil on all the important features exhibited. If the apparatus can be used for opaque projection the amount of illustrative material available is almost unlimited, for, besides the figures in atlases and textbooks, suitable illustrations may be cut from discarded medical journals and

the like. In this way the pupil can be taught to recognize the structures portrayed in any well-executed drawing.

3. Just as the child is required to draw maps in her geography class, so should the pupil nurse be required to draw anatomical diagrams either from memory or from illustrations. Outline charts of the human body may be given her and she should be asked to add the alimentary tract, the arterial system in its more salient features, the nerves, or the like.

4. The pupil should certainly be urged to correlate her own body with the pictures, models, and so forth which are presented to her. She can palpate most of her own bones, many of her muscles, can detect numerous pulses, observe the pupillary reflex, the secretion of saliva as it comes in little spirts from the submaxillary ducts, and so forth and so forth. In fact she will soon find that she is herself an excellent museum of anatomy and physiology.

5. It has become customary, largely, I suspect, because it is so convenient for those engaged in dissection to print the names of the parts directly upon the illustrations. Where this is not done, as in the case of the present volume, the pupil will find it an excellent exercise to attempt to identify the parts of the figures while covering up the legends.

TABLE OF CONTENTS

CHAPTER I

PAGE

INTRODUCTION 1

Conservation of Matter 1
Conservation of Energy 1
Matter and Elements 4
Compounds and Mixtures 5
Atoms and Molecules 5
Stability and Instability 6
Symbols, Formulæ, and Equations 6
Properties of Matter. Aquosity and Vitality 7
The Amœba 8
Properties of Protoplasm 11
Stimuli 12
Spontaneous Generation 12
Cells 13
Cell Differentiation 14
The Cell Doctrine 15
Development 15
Doctrine of Common Descent 16

CHAPTER II

CELLS AND SYSTEMS 17

Leucocytes 17
Epithelium 18
Connective Tissue 21
White Fibrous Tissue 22
Cartilage 23
Bone 23
Development of Bone 26
Systems 29

CHAPTER III

PAGE
CONTRACTILE TISSUE 36
Contractility 36
Cilia 36
Muscle 37
Source of Muscular Energy 37
Tonus 38
Excitation and Inhibition 40
Striated Muscle 41
Methods of Study 41
Effect of Load 43
Fatigue 43
Fatigue Substances 45
Fatigue Level 46
Plain Muscle 47
Cardiac Muscle 48

CHAPTER IV

ANIMAL MECHANICS 49
The Skeleton as a Whole 49
The Skull 49
The Hyoid Bone 59
The Vertebræ 59
The Ribs 66
The Clavicle 67
The Scapula 68
The Humerus 71
The Ulna and Radius 72
The Hand 72
The Pelvis 72
The Femur 78
The Patella 80
The Tibia and Fibula 83
The Foot 83

CHAPTER V

NERVOUS SYSTEM 85
The Neurone 85
Automatic Action 86

PAGE
Reflex Action 87
Tonus 88
Excitation and Inhibition 89
Describing a Neurone 90
Specific Nerve Energy 90
Complexities of the Reflex Arc 90
Reciprocal Innervation 91
Nerve Patterns 91
Centers 93
Nerve Impulse 94
Metabolism and Histologic Pictures 95
The Knee-jerk 96
Degeneration and Regeneration 96
Anatomic Relations and Arrangement of the Neurones . . . 97
Spinal Somatic Nerves 102
Cranial Somatic Nerves 103
Spinal Autonomic Nerves 106
Cranial Autonomic Nerves 107
Acquired Reflexes 107
The Cerebral Cortex 109
Cerebral Localization 113
Aphasia 115
The Cerebellum 116
Cortical Connections 117

CHAPTER VI

THE SENSES 120
Cutaneous, Subcutaneous, and Visceral Sensibility . . . 120
  Referred Pain 122
  Muscle Sense 123
  Tactile Discrimination 123
  Punctiform Distribution 124
Taste 125
Smell 126
The Eye 127
  Optics 127
  Accommodation 132
  The Pupil 133
  The Retina 133
  Color 134
  The Fovea 135

PAGE
The Blind Spot 135
Sense of Solidity 135
The Ear 138
The Semicircular Canals 141

CHAPTER VII

CIRCULATION 144
Introduction 144
The Circulation as a Whole 145
The Heart as a Pump 146
The Wave of Contraction 149
The Apex Impulse 150
Heart Sounds 150
Pericardium 150
Cause of the Heart-beat 151
Effect of Heat 152
Refractory Period 153
Automaticity 153
Tonus 153
Nervous Control of the Heart 154
Extensibility and Elasticity 156
Manometers 157
Determination of Blood Pressure in Man 161
Nervous Control of the Arteries 162
Capillaries and the Velocity of the Blood 167
The Veins 170
The Pulse 170

CHAPTER VIII

RESPIRATION 174
Introduction 174
The Lungs 174
Pressure, Volume, and Density of Gases 177
Repulsion and Gravity 178
The Mechanics of Respiration 179
Aspiratory Action of the Thorax 181
Muscular Mechanism of Respiration 182
Inspired and Expired Air 183
"Impure" Air 184

PAGE
Pulmonary Respiration 185
Cause and Control of Respiratory Movements 188
Bronchial Constrictors 190

CHAPTER IX

Blood and Lymph 191
The Blood 191
Hemolysis, "Laking" 191
Osmosis and Diffusion 191
Immunity 194
The Properties of Hemoglobin 195
Origin of Red Blood Corpuscles 197
Leucocytes 197
Clotting 198
The Lymph 200

CHAPTER X

Digestion 203
Introduction 203
Movements of the Alimentary Canal 204
Mastication 204
Swallowing 205
Peristalsis 205
Gastric Movements 205
Intestinal Movements 206
Defecation 208
Food-stuffs and Enzymes 209
Salivary Digestion 211
Glands 211
Nervous Mechanism 213
Ptyalin 214
Digestion and Absorption in the Stomach 215
Gastric Juice 215
Chemical Mechanism 218
Digestive Action 218
Absorption 220
Intestinal Digestion and Absorption 221
Pancreatic Secretion 221
Trypsin, Pancreatic Diastase, Lipase 224

PAGE
Intestinal Secretions and Enzymes 227
Absorption in the Small Intestine 227
Digestion and Absorption in the Large Intestine . . . 231

CHAPTER XI

LIVER, SPLEEN, AND EXCRETORY ORGANS 232
The Liver 232
Secretion of Bile 232
Liver and Carbohydrates 233
The Spleen 235
The Kidney 235
Secretion of Sweat 238

CHAPTER XII

INTERNAL SECRETION 239
Liver 239
Suprarenal Bodies 239
Testes and Ovaries 240
Pancreas 241
Thyroid Gland 241
Parathyroids 241

CHAPTER XIII

METABOLISM 242
Nutritional Equilibrium 242
Proteins 244
Adequate Proteins 244
Protein Sparing 244
Carbohydrates 245
Fats 246
Salts 246
"Vitamines" 246
Energy of the Food 247

CHAPTER XIV

HEAT REGULATION 249
Regulation of Heat Production . . 249
Regulation of Heat Loss 251

CHAPTER XV

PAGE
REPRODUCTION 254
Introduction 254
Testes and Spermatozoa 255
Fertilization 256
Ovaries, Ovulation, and Menstruation 259
Development of Fetus, Membranes, and Placenta 260
Nutrition of Fetus 263
Parturition 264
Lactation 266

APPENDIX

THE PLOTTING OF CURVES 267

ILLUSTRATIONS

FIGURE PAGE
1. Amœba 9
2. Amœba dividing into daughter cells 10
3. Leucocyte 17
4. Squamous epithelial cells. 18
5. Stratified squamous epithelium 19
6. Ciliated epithelial cells 20
7. Subcutaneous connective tissue 21
8. Section of tendon 22
9. Connective tissue cells containing fat 22
10. Cartilage 23
11. Section through the upper end of femur 24
12. Section of bone 25
13. The same more highly magnified 26
14. A bone cell 26
15 A. Developing bone 27
B. Centers of ossification 28
16–23. Diagrams to explain the mutual relations of the various "systems" 30–34
24. Purely diagrammatic representation of ciliary motion . . . 36
25. Diagrams illustrating contraction, relaxation, and tonus . . 38
26. Diagrams illustrating the nervous mechanism of tonus, excitation, and inhibition 39
27. Striated muscle fibers 40
28. Plain muscle fibers 40
29. Heart muscle cells 41
30. Diagram illustrating the mode of obtaining the curve of contraction of a muscle 41
31. Curve of muscle contraction 42
32. The ergograph 42
33. Ergogram showing effect of load 43
34. Curve of work 44
35. Ergogram showing fatigue 45
36. Diagrams representing ergographic records 46
37. Myogram of plain muscle contraction 48
38. The human skeleton 50

FIGURE PAGE
39. Skull, right semiprofile 51
40. Skull, lateral view 53
41. Skull, sagittal section 54
42. Temporal and buccinator muscles 55
43 A. Skull, external base 56
B. Skull, internal base 58
44. Hyoid bone 59
45. Fontanelles in the skull of a child at birth 60
46. Vertebral column 61
47. Thoracic vertebra 62
48. Anterior surface of abdominal wall 63
49. Sagittal section of head and neck 64
50. Deep muscles of abdominal wall 65
51. The ribs 66
52. The diaphragm 67
53. Diagram showing movement of diaphragm 67
54. Superficial and middle muscle layers of back 69
55. Arm and shoulder, in front 70
56. Arm and shoulder, behind 70
57. Development of os coxæ 72
58. Male pelvis 73
59. Female pelvis 73
60. Median section of female pelvis 75
61 A and B. Anterior and posterior views of the pelvis, showing ligaments 77–79
62. Thigh from in front 81
63. Flexors of thigh 81
64. Adductors of thigh 82
65. Thigh and leg from behind 82
66. Arches of the foot 84
67. Diagram of a neurone 86
68. An automatic nervous mechanism 86
69. Diagram of a reflex mechanism or "reflex arc" 87
70. Diagram of mechanism involved in tonus, excitation, and inhibition, direct and reflex 89
71. Diagram of reflex arc involving several motor neurones; no localized reflex center 91
72. Diagram of reflex arc involving several motor neurones; interposed neurones form localized reflex center 91
73. Diagram showing mechanism of reciprocal innervation . . . 92
74. Nerve cells from English sparrow 95
75. Diagram of cross section of spinal cord 97
76. Diagram of cross section of spinal cord, showing arrangement of the neurones 98

FIGURE PAGE
77. Cross section of a nerve trunk 99
78. Cross section of the spinal cord showing somatic and splanchnic neurones 100
79. Diagram of an autonomic ganglion 100
80 A. Spinal cord viewed from right side 101
B. Base of brain, spinal cord and nerves 102
C. Diagram of the somatic fibers of the trunk . . . 105
81. Diagram of the autonomic fibers of the trunk 106
82. Diagram of the autonomic fibers of the head 108
83. Motor areas of the cerebral cortex 114
84. Areas affected in aphasia 116
85. Diagram showing the relations of the cerebral and cerebellar cortices to the cranial and spinal nerves 118
86. Diagram of course of cutaneous fibers on reaching the cord . . 121
87. Diagram showing mechanism of referred pains 122
88. Diagram showing punctiform distribution of sensory endings . 125
89. Taste buds 126
90. Cells of the olfactory region 127
91. Diagrams showing effect of double convex lens on rays of light . 128
92. Diagram showing effect of varying convexity of lens upon the focal point 129
93. Diagram showing formation of image 129
94. Diagram illustrating emmetropia (2), myopia (1), and hypermetropia (3) 130
95. Diagram showing mechanism of accommodation 131
96. Diagram showing the nerve supply of the eye 132
97. Neurones of the retina 134
98. Muscles of the eyeball 137
99. Semidiagrammatic section through the right ear 139
100 A. Semicircular canals in the pigeon. B. Diagram showing mutual relations of semicircular canals 141–142
101. Schematic representation of the circulation 145
102. General view of the blood-vessels of the trunk, from before, in a male adult 147
103. The heart and great vessels from before 148
104. Diagram showing position of atrio-ventricular bundle . . . 149
105. Diagram of the heart and pericardium 151
106. Tracing showing the effect upon the force and rate of the heart of altering the temperature of the circulating liquid . . . 152
107. Diagram showing effect on output of variations in the tonus of the cardiac muscle 154
108. Cross section of the wall of an artery and a vein 155
109. An arteriole 156
110. Capillary vessels 157

FIGURE PAGE
111 A-D. Diagrams illustrating the principle of the manometer . 157-159
112. Diagram of model of the heart and vessels 160
113. Pressure changes in the arteries 161
114. To show the effect on heart-rate and blood pressure of destroying the tonic action (by section) of the vagi 163
115. To show the effect upon heart-rate and blood pressure of stimulating the peripheral end of the cut vagus 164
116. To show the effect of stimulation of the peripheral end of the cut accelerators upon the heart-rate and blood pressure . . 165
117. Scheme of a vaso-constrictor reflex 166
118. Diagram showing nervous control of the heart and arteries . . 167
119. Diagram illustrating Leonardo da Vinci's law 168
120. Diagram illustrating the application of da Vinci's law to the circulation 169
121. Valves in veins 170-171
122. Sphygmogram 172
123. Simultaneous tracings of the carotid and jugular pulses . . 172
124. Diagram showing termination of a bronchial tube . . . 175
125. Diagram showing relation of lungs to pleura 176
126. Diagram illustrating the mechanism of the barometer . . . 179
127. Diagram showing the pressure relations in the thoracic cavity . 180
128. Diagram of the nervous mechanism of respiration . . . 188
129. Cross section of a bronchiole, showing broncho-constrictors . . 189
130. Diagram illustrating osmotic relations 192
131. Diagram illustrating osmotic relations in plants 193
132. Diagram showing the relation of the cells to the blood and lymph capillaries 201
133. Diagram showing the different parts of the alimentary canal and the glands opening into it 204
134. Diagram illustrating peristaltic movement 205
135. Rhythmic segmentation 207
136. Diagram illustrating changes of pressure during straining . . 209
137. Schematic representation of a gland 212
138. Sections of the submaxillary gland of the dog 213
139. Diagrammatic view of carbohydrate digestion 215
140. A. Glands of the stomach 216
B. Surface view of mucous membrane of stomach 217
141. The portal system 219
142 A. Arteries of stomach and adjacent organs 220
B. Section through pyloric ring of stomach 221
143. Abdominal viscera and nerves 222
144. Diagram illustrating the digestion of proteins 225
145. Plicæ circulares of intestine 228
146. Surface view of small intestine 228

FIGURE PAGE
147. Section of the human intestinal mucous membrane showing villi and intestinal glands 229
148. Diagram showing structure of intestinal villi 230
149. Diagram showing the relations of the liver cells to blood vessels, lymphatics, and bile ducts 234
150. Diagram showing structure of glomerulus 236
151. Diagram of the urinary bladder 237
152. Human spermatozoa 257
153. Diagram of the male organs of reproduction 257
154. Diagram of the female organs of reproduction 257
155 A. View of female pelvic viscera from above 258
B. Female pelvic organs, sagittal section 259
156. Diagram of ovum before segmentation 260
157. Diagram of ovum after segmentation has begun ; two-cell stage . 260
158. Diagram of ovum after a considerable amount of cell-division has taken place 261
159. Diagram showing the beginning of development of embryo . . 261
160. Diagram showing the approaching edges of the pit in which the embryo lies 261
161. Diagram showing embryo, membranes, and placenta 262
162. Diagram showing relations in placenta 262
163. Diagrams showing the peculiarities of the fetal circulation . . 263
164. Dissection of the lower half of the human mamma during the period of lactation 265
165. A urine chart 267
166. A patient's temperature chart 268
167. Chart made by a self-recording thermometer 269

ANATOMY AND PHYSIOLOGY FOR NURSES

CHAPTER I

INTRODUCTION

Conservation of Matter. — If a candle be lighted, it gradually burns up and there is apparently nothing left of it. It would at first sight seem that the substance of the candle had been destroyed, but this is not the case, and it is to the credit of the great chemist Lavoisier that he first explained this and similar phenomena. He found that the gaseous products of the combustion of the candle weighed no less than the candle itself had originally weighed, or, in other words, that there was no destruction of matter but only change. Now a law of nature is merely the expression of human experience, and as the experience of Lavoisier and of all other investigators since his time has invariably been that although matter can be changed it cannot be destroyed, we feel justified in making the important generalization that matter is indestructible, and this generalization we call the Law of the Conservation of Matter.

Conservation of Energy. — Corresponding to this Law of the Conservation of Matter is another law equally far reaching and equally important. This is the Law of the Conservation of Energy. To give a definition of energy would perhaps be difficult and certainly unsatisfactory. A few examples will, however, show what is meant. If a stone be allowed to fall through a certain distance, say from the top of the blackboard to the floor, there will be a certain definite effect produced. The air through which it falls will be heated by the friction and the place where it strikes will be heated by the impact. If the same stone be raised again to the top of the blackboard and again allowed to fall, the air and ground will become heated as before. Now if we were to measure the heat generated by this falling body, it would be found that the amounts of heat generated in the first case and in the second case were exactly equal. Furthermore, by varying the experiment somewhat, we should find that the amount of heat varied with the weight of the stone and the distance through which it falls. Thus, the greater the weight or the greater the distance, the greater the amount of heat generated. When the stone has reached the floor, we see that it is incapable of falling farther; it has lost the power of falling, or, as we say, the energy of position. In the place of this energy of position, we have obtained a certain amount of heat.

In raising the stone to the top of the blackboard, we do a certain amount of work. This amount of work depends on the weight of the stone and on the height to which it has been raised. In raising the stone, we give it the power of falling, that is, energy of position. In other words, from a definite amount of work a definite amount of energy of position can be obtained, and from this a definite amount of energy of motion, and from this a definite amount of heat. Thus starting with a given amount of work, a definite amount of heat can be obtained, no more and no less.

Let us consider another example. The power of coal to burn is like the power of a stone to fall. From a definite amount of coal a definite amount of heat can be obtained; this heat will convert a definite amount of water into steam, and by this means we can run an engine at a certain definite speed. This engine can be made to work a dynamo which, in turn, runs an arc light or an electric car or an electric furnace. Here we have an interesting series of phenomena consisting essentially in the change of one kind of energy into another.

Thus the chemical energy of the coal is converted into heat, this into the motion of the expanding steam which passes its motion on to the piston of the engine, this motion is converted into electrical energy and this electrical energy is converted into energy of motion in the case of the street car, into light in the case of the arc light, into heat in the case of the electric furnace.

Throughout this long series of events no energy has been destroyed, though much may have been wasted, owing to the imperfections of our methods. If then we take the energy of the electric furnace and add to it the amount of energy which we know to have been wasted, we shall find that it is exactly equivalent to the energy set free by the burning coal.

Again photic energy, or the energy of light, may be converted into chemical energy, as in the formation of starch and wood in plants exposed to the sun. The wood is burned and its chemical energy is converted into heat. The starch is eaten and its chemical energy is converted into the heat and motion of the animal which has eaten it.

All those various kinds of energy may be grouped under two great heads, the stored-up or potential energy, and the active or kinetic energy.

Potential energy	energy of position chemical energy
Kinetic energy	heat light motion, etc.

It is not difficult for the physicist to calculate exactly how much of a particular form of energy is equivalent to a fixed amount of any other kind of energy. Energy can be measured, and although it has been found that we can convert it from one form into another, we have never been able to destroy any part of it. Thus we feel justified in making another important generalization, namely, that energy may change in form but is indestructible. This is the Law of the Conservation of Energy.

Matter Elements. — The forms in which matter occurs are innumerable: wood, glass, cloth, and the like; it is the work of the chemist to study and analyze these various forms of matter. The chemist has found that many of these forms of matter may be broken up into simpler forms which he is unable to decompose farther by any means with which we are acquainted at present. Those simpler forms which he cannot decompose he calls elements, while all those substances which are not elements, that is, which he can decompose into elements, he calls compounds.

As examples of elements we have carbon, iron, sulphur, and the gases: nitrogen, hydrogen, oxygen, and so forth.

All together about 80 elements have been described.

The relation between the various elements differs from that between the various forms of energy in that the elements are not only perfectly distinct but cannot, except perhaps in a few cases, be converted one into another, as is the case with the various forms of energy. The alchemists believed that this could be done and that the element *iron* could be converted into the element *gold*. Although the supposition is not at all irrational, it is entirely speculative.

Compounds and Mixtures. — As examples of compounds, we have water, which is a compound of hydrogen and oxygen; we have iron rust (oxide of iron), which is a compound of iron and oxygen; we have iron sulphate, which is a compound of iron and sulphur. These compounds are very different from the elements which compose them. The elements as such have lost their individuality and have been completely merged into a new substance. In this respect chemical compounds differ from mixtures. The mixture is a simple association of substances. Thus if we mix iron and sulphur, they remain iron and sulphur. The sulphur can be dissolved out by certain liquids, leaving the iron behind, while the iron particles can be removed from among the sulphur grains by means of a magnet. On the other hand, iron sulphide (Fe_2S_3) is not attracted by the magnet nor is it soluble in the same substances as sulphur. Again, the oxygen and nitrogen of the atmosphere do not form a chemical compound, but are only mixed together.

Atoms and Molecules. — There are a great many facts known, which it would not be profitable for us to discuss, which have led chemists and physicists to an important conception with regard to the constitution of matter, namely, the conception of the molecule and of the atom. To be sure, no one has ever seen either of these things, but the assumption that they exist explains so many chemical and physical phenomena that we feel justified in believing that the assumption is a legitimate one. According to this conception, matter is not continuous but is made up of minute molecules or particles. The fact that these molecules do not fall apart is expressed, but not explained, by saying that they are held together by "cohesion." Each molecule in turn consists of one or more atoms, which may be of the same element or of different elements, according as the substance, which is made up of the molecules in question, is an element or a compound. Exactly how the atoms are held together to form the molecule, we do not know. We have, however, given a name to the property, and we say that the atoms are held together by their chemical affinity, but remember that this phrase "chemical affinity" is not in any sense an explanation.

Stability and Instability. — This property of atoms, of uniting to form compounds, varies in character with the atoms and with certain surrounding conditions. Certain compounds disintegrate into their component atoms only when highly heated or when subjected to other kinds of severe treatment, while other compounds break up on the slightest provocation, so to speak. The former class is spoken of as stable, the latter as unstable. There are thus varying degrees of stability and, of course, of instability.

Symbols, Formulæ, and Equations. — Chemists have agreed upon a particular method of representing graphically the various chemical substances and their reactions. For example, the reaction which takes place when coal or carbon is burned is expressed by the equation $C + O_2 = CO_2$. Where C and O are the symbols for carbon and oxygen, respectively, CO_2 is the formula for carbon dioxide and the whole expression is known as a chemical equation. But on the basis of the atomic theory this equation is made to express still more. It means that one molecule of carbon combines with one of oxygen to make one molecule of carbon dioxide. So also $2\,H_2 + O_2 = 2\,H_2O$ means that two molecules of hydrogen combine with one molecule of oxygen to make two molecules of hydrogen monoxide, or water. These symbols also express the facts that each oxygen molecule is composed of two atoms of oxygen and that each molecule of carbon dioxide is composed of three atoms, two of oxygen, and one of carbon, and similarly in the second equation.

Properties of Matter: Aquosity and Vitality.—Every substance possesses certain properties, some of which it shares with all other forms of matter, some of which are peculiar to itself. For example, take water. In addition to its possessing weight and occupying space, properties common to all forms of matter, water has numerous properties of its own. It has a certain density; it is formed under certain conditions, and under certain other conditions it is decomposed; it dissolves certain substances, but other substances are not dissolved by it; it solidifies at 0° C. and is converted into a gas at 100° C., and so on. All these properties may be summed up conveniently under the term "aquosity." To say that water possesses aquosity is merely to say that water possesses the properties of water; it explains nothing, it is merely a convenient form of expression.

Now there is a certain class of substances known as protoplasm which exhibits properties peculiar to itself. Those properties may be conveniently summed up under the term "vitality." Here again, to say that protoplasm possesses vitality does not explain anything. We merely state that protoplasm possesses the properties of protoplasm and add that, for convenience, we call these properties taken collectively "vitality."

This analogy between water and protoplasm, between aquosity and vitality, is not a fanciful one. It is drawn to emphasize the fact that there is nothing especially mysterious about the phenomena of life, and that the properties of growing and moving which we find in protoplasm are not one whit more incomprehensible to us than are the properties exhibited by water in freezing and by iron in rusting. That the properties of protoplasm should be far more numerous and complex than those of water seems only natural when we consider the immensely greater complexity of the protoplasmic molecule; for as we represent water by the formula H_2O, so the formula of the protoplasm is $C_{726}H_{1171}N_{194}O_{214}S_3$.

The Amœba. — Let us examine more closely the properties of protoplasm, and for this purpose let us turn to one of the simplest forms of living things with which we are acquainted. There is a little organism called the amœba (Fig. 1) which is not infrequently found in stagnant water and is essentially a little chunk of protoplasm endowed with the properties of protoplasm, *i.e.* endowed with vitality, or, in other words, with life.

Viewed through the microscope, the amœba is seen to consist of a translucent, semifluid, jelly-like substance (cytoplasm) which is constantly changing its form and which contains a more solid body, of a more constant shape, and of somewhat different chemical composition, the nucleus.

If we watch the amœba long enough, we shall see that the cytoplasm of the amœba is in almost constant motion, flowing now in this direction, now in that, sending out long processes or pseudopodia and then either retracting them again or flowing into them and so moving about from place to place. This property may be called motility.

By means of these "amœboid" movements, as they are called, and by means of its pseudopodia, the amœba is brought into relation with many objects in its neighborhood. We see that the contact of the object with a pseudoped usually causes some sort of response in the latter. If, for instance, the object be a hot wire, the pseudoped will be promptly retracted and indeed the whole organism may contract into a motionless, globular mass.

Here we see an illustration of two important properties of protoplasm. They are the power of responding to external influences, and that property by means of which the response is not confined to the point stimulated but is spread throughout the amœba and excites a response in all parts of the organism. These properties may be called irritability and conductivity, respectively.

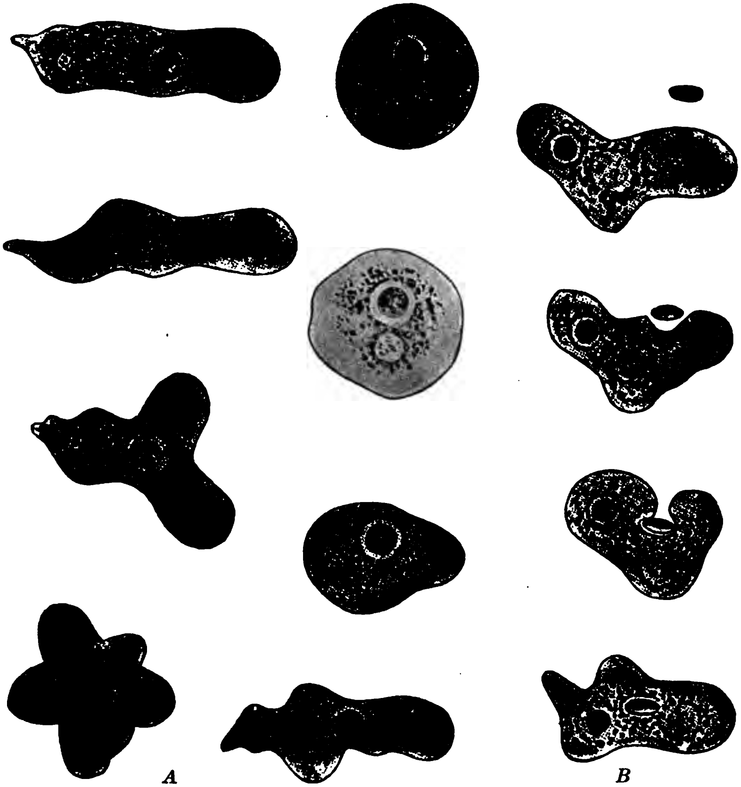

Fig. 1. — *A*. An amœba, showing different shapes assumed by it when crawling. *B*. An amœba eating a microscopic unicellular plant. (Verworn.)

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If we continue to watch a moving amœba, we may see it approach a diatom or some other small vegetable organism, and coming into contact with the plant, the amœba flows around it, engulfs it, and passes on. The diatom is then seen to lie in a small cavity in the protoplasm of the amœba, and soon to become surrounded by a clear, transparent fluid. In the course of time it becomes disintegrated and dissolved, leaving only its hard, resistant shell.

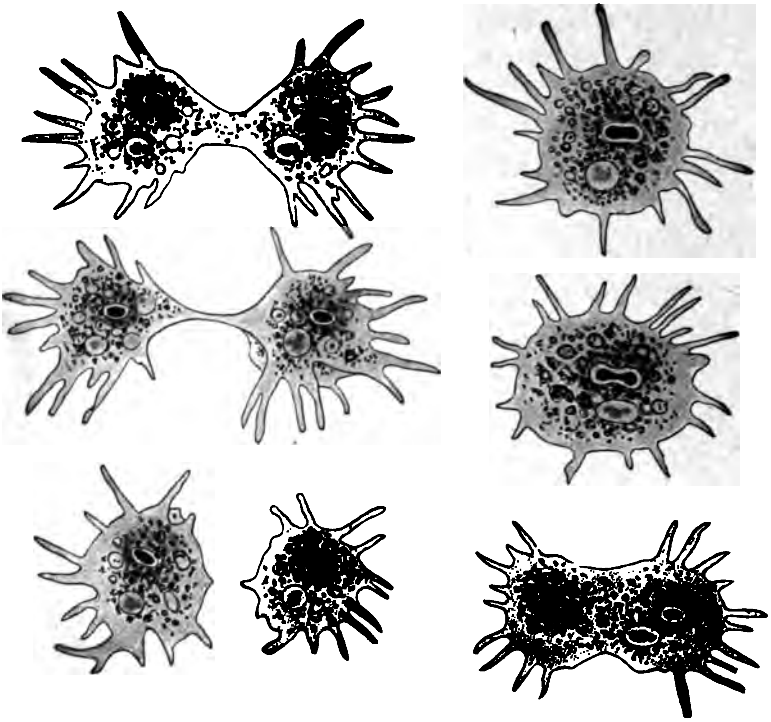

FIG. 2. — Amœba polypodia in six successive stages of division. The dark spot with a white margin in the interior is the nucleus. (F. E. Schulze.)

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As the amœba moves onward, this shell gradually finds its way to the surface and is soon pushed out and left behind. Thus we see that the amœba swallows or ingests other organisms, which are in part dissolved and distributed throughout its own substance and become in fact part of the living protoplasm of the amœba. These phenomena are spoken of as nutritive processes or nutrition. Of these the fundamental feature is that protoplasm, brought into contact with certain other substances, sets up in these substances a series of changes which results in the conversion of those other substances into protoplasm.

As the amœba is constantly adding new protoplasm to itself, it must, of necessity, increase in size or grow. This process is not continued indefinitely, for after a time the amœba elongates, becomes dumb-bell shaped, and finally divides into two amœbæ, each retaining approximately one half of the original cytoplasm and one half of the original nuclear material, and each the exact counterpart of the parent excepting only in regard to size. Here we see the phenomenon of reproduction in one of its simplest forms (Fig. 2).

Properties of Protoplasm. — To summarize briefly, we may say: that the properties that characterize the class of substances which we call protoplasm, properties which, when taken collectively, we call "vitality," are five in number, namely,

motility or contractility,
irritability,
conductivity,
nutrition,
reproduction.

If we heat or poison the water in which the amœba is, we kill the amœba. Then although the substance of the amœba no longer exhibits the properties termed "vitality," we still call it protoplasm and distinguish the two by calling the one living and the other dead protoplasm. As far as we can tell, the two kinds of protoplasm are identical in composition and structure. What this change is which is so subtle that, with the means and methods at our disposal, we are unable to detect it, we do not know. The diamond when heated turns into charcoal, and the properties of these two forms of pure carbon are obviously very different, but the difference in the structure of the molecule is quite unknown to us. The same is true of red phosphorus and of other substances which have what are known as allotropic forms. Hence, although we do not know in what respect living and dead protoplasm differ, yet we see that the change from the one to the other is not so unique as might at first appear. There are many analogous changes which other forms of matter undergo, both elementary and compound.

Stimuli. — The property of irritability is the power of responding to changes in environment. A change which is capable of calling forth a response is known as a "stimulus." There are many sorts of stimuli, such as chemical, thermal, mechanical, and electric stimuli; also sound and light are in some cases effective.

Spontaneous Generation. — The question of the origin of the living from the nonliving was for a long time much debated. It was not difficult to show that horsehairs did not turn into worms, but since it was well known that if perfectly clear bullion was allowed to stand, it soon became cloudy and on examination with the microscope was found to be swarming with minute organisms, the question very naturally arose, Where did these organisms come from?

Some believed that the organisms were spontaneously generated in the fluid, and it was some time before it was proved by Professor Tyndall and others that these organisms were all derived from preëxisting organisms floating in the air. Other cases of supposed spontaneous generation were disproved one by one, and now we can assert that every organism is the offspring of a preëxisting organism.

It is not to be supposed that the possibility of the origin of living matter from nonliving matter is hereby denied. Indeed we feel pretty sure that, once upon a time, living matter arose from a combination of its elements, just as water arose from a combination of hydrogen and oxygen which once existed as glowing gases in the earth's atmosphere. We feel pretty sure that we know how water was formed, and we can repeat the process in the laboratory, and we believe that protoplasm came into existence in some similar fashion; but just how the formation of protoplasm was brought about we do not know, and we might not be able to repeat the process if we did know. What Tyndall and others have shown, then, is, that at this stage of the world's history the conditions are such that all living matter is derived from preëxisting organisms.

Cells. — In the latter part of the eighteenth century, Schleiden, a German investigator, discovered that the tissues of plants were composed of small masses of protoplasm, each having a nucleus and each separated from its neighbors by a firm cellulose wall. These nucleated masses, each in its cellulose compartment, he called "cells."

Soon after this Schwann, a fellow pupil of Schleiden, found that the tissues of animals were also composed of similar nucleated masses of protoplasm which were, however, much less clearly defined, owing to the absence of the hard cellulose cell-wall so characteristic of the vegetable cells. The microscopical studies of these and of other investigators have shown that all organisms, be they plants or animals, are composed of cells. In the lowest forms, such as the amœba or the bacteria, the organism consists of a single cell. It is a unicellular organism.

Cell Differentiation. — When we examine the many-celled or multicellular organisms, we find that the lowest are no more than an aggregation of similar cells forming, it is true, a single collection, but each cell living its own life almost independently of the others. As we pass on to the more complex organisms, we find that the cells are no longer exactly alike. Some have taken upon themselves one function, some another. Some possess vibrating hairs (cilia) by means of which a current of food-bringing water is created; others act as reproductive organs, and so forth. The power of each cell to do certain work increases, but the cell loses in other ways.

As we proceed higher and higher in the scale of complexity, we find that the cells which compose the organisms show progressively more and more points of difference, each losing much of its power of independent existence but gaining in its power of carrying out certain special functions. The amœba is a free and independent being, a cellular Robinson Crusoe, a Jack-of-all-trades but a master of none; the nerve cell is a specialist, most proficient in its own line of work, but absolutely dependent for its existence on the coöperation of other specialists. In this progression no new properties appear, only the old ones become more and more highly developed, and more and more restricted in their occurrence, that is, more monopolized by particular groups of cells, until in the mammalia we find: contractility, confined almost entirely to muscle cells; irritability, to epithelial and nervous tissues; ingestion, to a few classes of cells such as the white blood corpuscles; digestion, to the cells of various glands; reproduction, to the germ cells of the ovary and testis. To these cells only one common property remains, namely, that of converting suitably prepared food into their own cell substance, and thus repairing the wear and tear which every cell experiences to a greater or less degree.

The Cell Doctrine. — We may liken the multicellular organism to a colony of ants, a hive of bees, or a community of human beings. These are made up of distinct individuals coöperating for the welfare of the whole. The life of such an aggregation would be the sum of the lives of the component parts. This conception of the constitution of living things, that the multicellular organism may be regarded as a community of cells and that all the varied activities of the body are the result of the activity of the cells which compose it, is known as the cell doctrine. This point of view plays a rôle of enormous importance in biological and medical science.

We have seen that all life springs from preëxisting life. Now in the light of the fact that all forms of life are composed of separate units or cells, we may modify our statement and say that every cell springs from a preëxisting cell.

Development. — Shortly after the discovery of the cell came that of the ovum, and the studies of the embryologists soon revealed the fact that all organisms, even the most complex, arise by a process of repeated division of this one cell. In brief the history of the organism is this: it begins as a single cell, the fertilized ovum. After fertilization the ovum divides and subdivides again and again. At first the cells are all alike, but soon differences begin to appear. The cells multiply, the differences between them increase. They arrange and rearrange themselves, the organism as a whole passing through a series of developmental changes, beginning with the simple and ending with the complex. Thus, in the development of the adult human being from the fertilized ovum there is, first the embryo, which resembles in turn the amœba, the fish, the mammal.

Then the baby is born with certain striking ape-like characteristics, which are soon outgrown; and the child exhibits the primitive instincts of its savage antecedents.

What is the significance of these changes? Why does the ovum resemble the amœba and why do children resemble primitive folk?

Doctrine of a Common Descent. — There is a shrewd supposition that all forms of life are descended from the same stock. Of this we have, of course, only circumstantial evidence, but the strength of this evidence is very great. The phenomena of the development of the adult form would then be only an instance of heredity, of heredity in the broad sense of the word. In this sense heredity means, not only that the son is like his parents, or that he bears resemblance to all his ancestors near and remote, but that the offspring, in its development from the ovum to the adult form, recapitulates in abbreviated form the whole history of the human race from the one-celled amœba-like form to the adult human being. This, then, is what we mean by heredity in a broad sense: not only that we resemble our parents or our most remote human ancestors, but that, at one time or another, we betray our relationship to the whole living world. This is the doctrine of descent by which we explain the phenomena of development and many other biologic phenomena.

CHAPTER II

CELLS AND SYSTEMS

We have seen (page 14) that in the more complex organisms the cells are not all alike, but that they exhibit a marked specialization. We shall now describe the more important types of the cells which go to make up the human body.

Leucocytes. — Of all the cells of the body the leucocytes (Fig. 3) most resemble the amœba. They have all the properties of the amœba except the power of reproduction, and differ also in the fact that they require such a complicated medium as blood to live in. The leucocyte possesses a nucleus and granular protoplasm. It can move from place to place in the flowing, amœboid fashion and can even squeeze through the tissues of the body between the stationary cells, whence it has acquired the name of "wandering cell." The leucocyte is also capable of ingesting solid particles, which are often seen lying in its cytoplasm. In this way they may take up and destroy any bacteria which they may encounter either in the blood stream or in the course of their wanderings through the tissues and may then play a valuable rôle in combating invading disease germs.

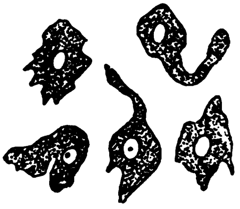


Fig. 3. — A leucocyte sketched at successive intervals of a few seconds to illustrate the changes in form due to its amœboid movements. (Martin.)

Epithelium. — The second form of cell is the epithelial cell. It is usually not motile, though some forms are able to change their shape but not their location, being, therefore, unable to wander. These cells are all closely crowded together, or in other words there is but little "intercellular substance" between them. Tissues which are composed of epithelial cells are known as epithelium. The latter usually covers some surface which is in direct or indirect communication with the surface of the body. For example, epithelium lines the entire digestive tract including all the glands which open into it, also the respiratory passages, the reproductive and urinary passages. The cells which cover the surface of the body differ from the epithelium of the parts already referred to in that the superficial layers are dried and horny, owing to exposure to the drying effect of the atmosphere. The epithelial cells may be subdivided still further according to structure and function as follows:

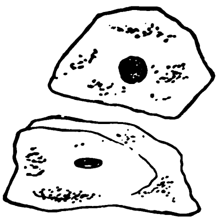


Fig. 4. — Squamous epithelial cells. Mucous membrane of the mouth of a rabbit. (Stoehr.)

Simple, *squamous* epithelium consists of flat, scale-like cells which are united at their edges by an extremely small amount of intercellular substance (Fig. 4). Seen in the flat, they present the appearance of mosaic; seen on edge, the cells appear spindle-shaped, being thickest in the center where the nucleus lies. This type occurs in the lungs and in the glomeruli of the kidney.

Simple, *columnar* epithelium consists of a single layer of elongated cells. It is this variety which has developed the power of secreting or of absorbing to a marked degree. These are the cells which line the alimentary tract and its glands. They manufacture and pour out upon their free surface liquids which differ in different localities, here saliva and there gastric juice; in another place they absorb the food after it has been liquefied by these secretions.

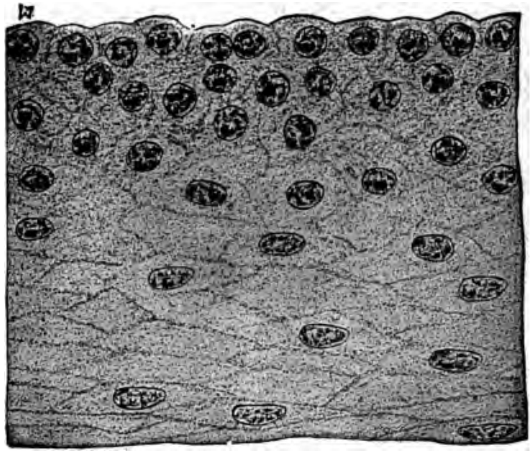


FIG. 5. — Stratified squamous epithelium from cat's œsophagus. (Bailey.)

Sometimes the cells occur in more than one layer (*stratified* squamous) as for example in the skin, cornea and elsewhere (Fig. 5). The respiratory passages are lined with epithelium, the superficial layer of which is provided with vibratory hairs (cilia) and it is therefore known as *ciliated* epithelium (Fig. 6).

Finally there are the so-called neuro-epithelial cells, which are modified to receive and respond to certain stimuli by which other epithelial cells are unaffected. Such, for example, are the rod and cone cells of the retina, which are stimulated photo-chemically by the light and which are intimately connected with the fibers of the optic nerve; also the cells which form the organs of taste (p. 127), which are stimulated chemically by the food and which are connected with the nerve fibres which mediate the sense of taste. Very similar to the squamous epithelium are the so-called endothelium which lines the blood vessels and capillaries and the mesothelium of the pleura, pericardium, and peritoneum. The distinction between epithelium, endothelium, and mesothelium is one of origin only. The three tissues are derived from different sources, but as their function and structure are identical the difference is in the present instance unimportant. They form a delicate, smooth, moist lining for the tubes or cavities which they inclose.

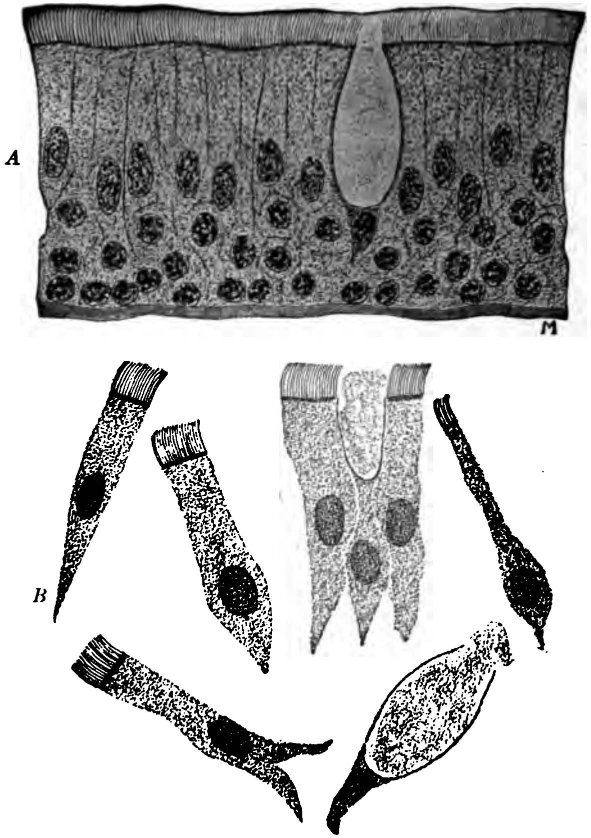


FIG. 6. — *A*. Stratified columnar ciliated epithelium from human trachea. A mucous ("goblet") cell is also present.
B. Isolated ciliated cells and goblet cells from dog's trachea. (Bailey.)

Connective Tissues. — Just as some of the cells of the snail or oyster secrete the shell or the cells of the coral secrete the stony skeleton of these polyps, so do certain cells of more complex animals have for their function the formation of intercellular substances, which are more or less tough and firm. These cells and their products constitute the connective tissue, which, as its name implies, binds together the various parts of the body and also supplies a framework for the organs and gives form and firmness to the body as a whole.

The connective tissue cells differ among themselves chiefly in respect to their products, the intercellular substance, which separates the cells into larger or smaller groups and may be of considerable quantity. The more important varieties of this tissue are (1) white fibrous tissue, (2) yellow elastic tissue, (3) cartilage, and (4) bone.

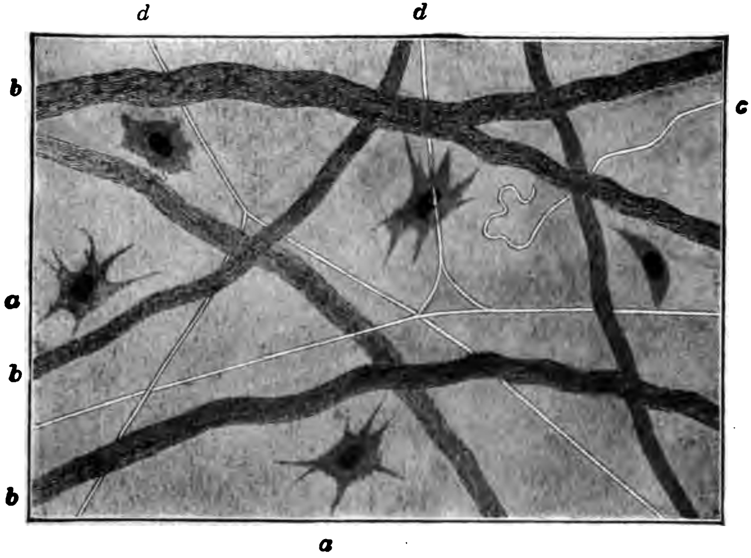


Fig. 7. — Subcutaneous connective tissue of rabbit, showing: *a*, connective tissue cell; *b*, bundles of white fibers; *c*, yellow elastic fiber with curled-up broken end; *d*, elastic fibers showing Y-shaped branching. (Bailey.)

White Fibrous Tissue consists of bundles of white fibers (Fig. 7) coursing through a structureless matrix in which lie the cells (Fig. 8). Both fibers and matrix are the products of the cells. On boiling they are converted into gelatin.

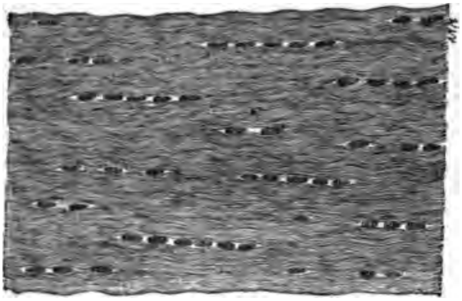


FIG. 8. — Longitudinal section of tendon of frog's gastrocnemius. The nuclei of the flattened cells are seen lying in rows between the connective tissue fibers. (Bailey.)

If the arrangement of the fibers is loose, we have what is known as areolar tissue. If the tissue elements are closely packed together, there are formed such resistant structures as ligaments and tendons. It is in the areolar tissue that fat is at times deposited. Here the cells become so swollen with droplets of oil (see Fig. 9) that their nuclei are pushed far to one side and the cytoplasm becomes relatively inconspicuous.

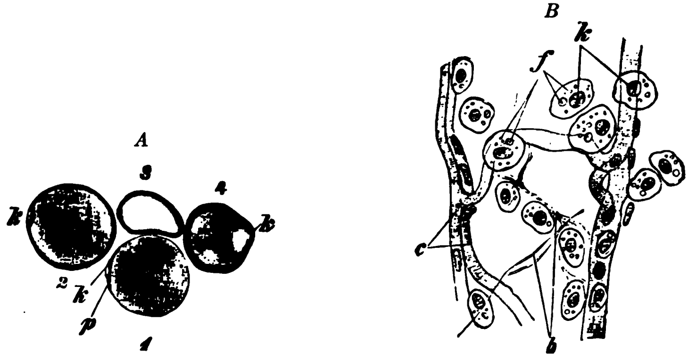


FIG. 9. — Fat cells from the axilla. *A*, of a well-nourished individual: *p*, traces of protoplasm in the vicinity of the flat nucleus, *k*. *B*, of an emaciated individual: *k*, nucleus; *c*, blood capillaries; *f*, fat droplets; *b*, connective tissue bundles. (Stoehr.)

In the second sort of connective tissue, *yellow elastic tissue*, the fibers are not white and inextensible, but yellow, extensible, and elastic. This tissue is abundant in the walls of the arteries, where its properties of extensibility and elasticity play an important rôle.

Cartilage differs from elastic tissue in that the ground substance is firm and dense; on boiling it yields chondrin and the cells are relatively few (Fig. 10). In some varieties of cartilage the presence of a considerable number of elastic fibers renders the cartilage more or less flexible; as, for example, the cartilage of the ears.

Bone is a connective tissue impregnated with lime salts, chiefly phosphates. These salts constitute about two thirds of its weight. Bone is either dense like ivory (compact) or spongy with obvious interstices (cancellated) (Fig. 11). The outer layers of all bones are compact, and the inner part is generally cancellated, but the shafts of the long bones are entirely made up of the compact substance except at the center, which is hollow and filled with yellow marrow. Externally, the bones are covered except at the joints with a fibrous membrane containing numerous

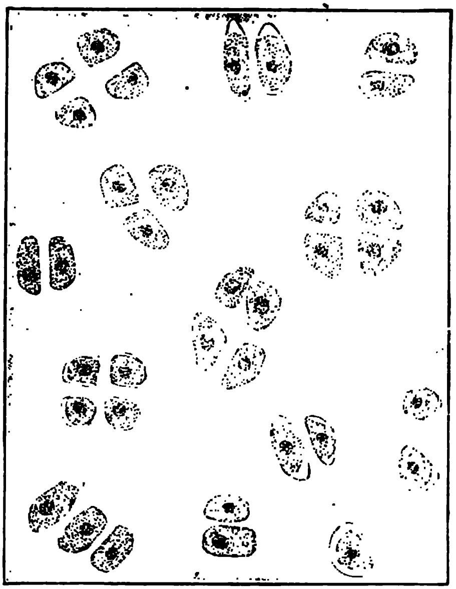


FIG. 10. — Cartilage from hip joint of frog. Groups of cartilage cells in an apparently homogeneous matrix. (Bailey.)

blood vessels, the periosteum. Bone is made up of layers, and between the layers lie the cells. These layers are either concentric with reference to the blood vessels or parallel to the surface of the bone. The cells lie in little pockets which are connected with the canals containing the blood vessels and with each other by a system of minute channels (Figs. 12, 13, 14).

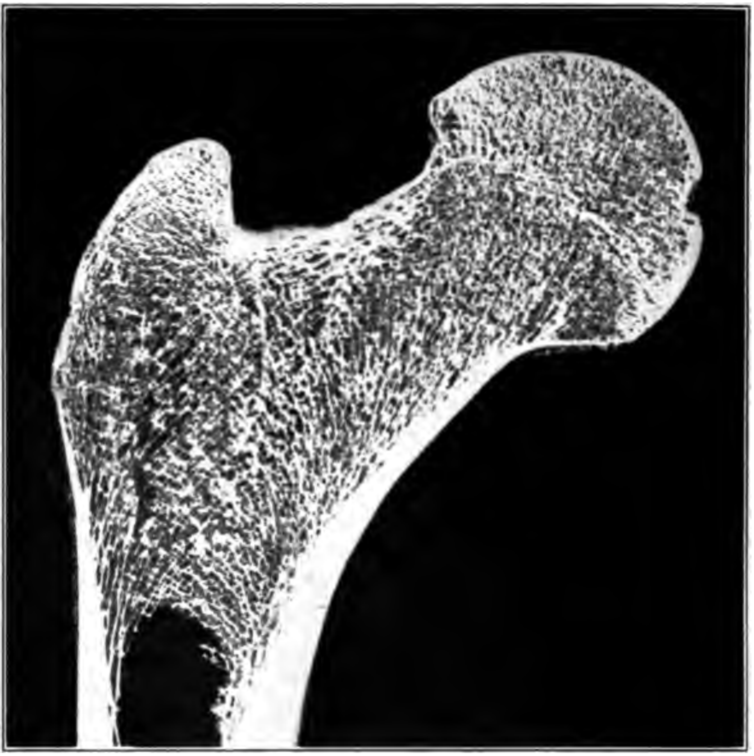


FIG. 11. — Section through the upper end of femur showing spongy structure, the lamellæ and trabeculæ being so arranged as to give the greatest strength. (Zaaijer.)

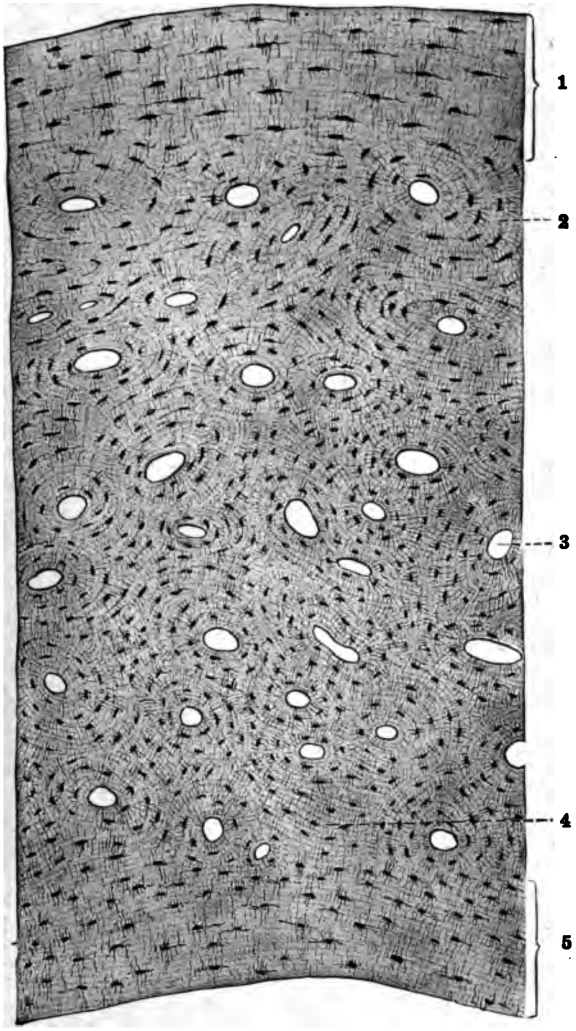


Fig. 12. — Transverse section of the shaft of a long bone, showing all the lamellar system. 1, outer circumferential lamellæ; 2, Haversian or concentric lamellæ; 3, Haversian canal; 4, interstitial lamellæ; 5, inner circumferential lamellæ. (Boehm and Davidoff.)

Development of Bone. — In the early stages of development the skeleton is represented by structures of cartilage or of connective tissue which are subsequently converted into bone. The process by which this is brought about depends upon the tissue originally present. The ossification of the connective tissue takes place in the following way. The tissue itself, as already stated, is composed of small bundles of white fibers lying in a structureless ground substance. At one or several points in this " bone pattern " the bundles of fibers become calcified (*i.e.* lime salts are deposited in them). This forms what is called a center (or centers) of ossification (Fig. 15 *B*). Between the bundles of calcified fibers the connective tissue is vascular and rich in cells. Along the surface of the calcified fibers certain of these cells (osteoblasts) arrange themselves in a single layer. These osteoblasts secrete a thin plate of bone between themselves and the calcified fibers. Although the bulk of this deposit is on the side of the osteoblasts which is nearer to the already calcified fibers, it is not confined to this locality, so that the cells soon become inclosed between two layers of their own making.

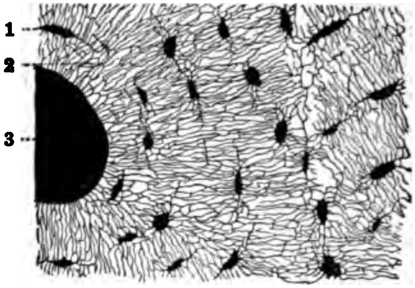


FIG. 13. — More highly magnified transverse section from the shaft of a human femur. 1, lacuna; 2, canaliculi; 3, Haversian canal. (Boehm and Davidoff.)

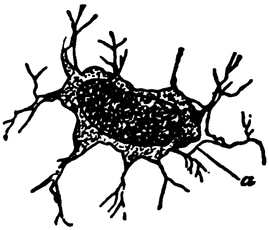


FIG. 14. — Bone cell lying in cavity of bone (lacuna) which it completely fills except at *a* where the cell has shrunken away from the wall of the lacuna. (Joseph.)

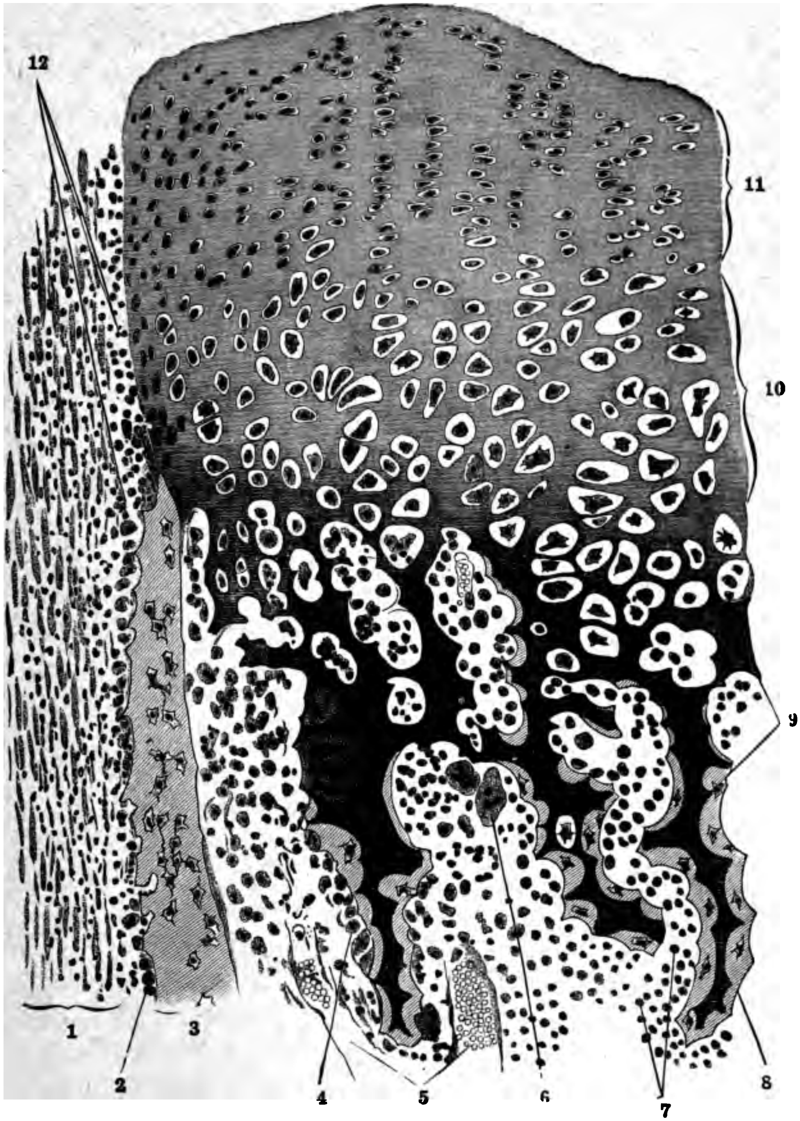


FIG. 15 *A*. — Developing bone. Longitudinal section of the first phalanx of the human fœtus (four months). 1, periosteum; 2, osteoblasts; 3, perichondrial bone; 4, osteoblasts; 5, blood vessels; 6, osteoclasts; 7, marrow cells; 8, endochondral bone; 9, calcified matrix of hyaline cartilage; 10, hyaline cartilage (cells enlarged); 11, hyaline cartilage (cells in groups); 12, osteogenetic tissue. (Stoehr.)

They now cease active bone making and become the ordinary bone cells (or " corpuscles ") of the adult bone. The bone which results from this process is of the spongy variety.

If the bone patterns are first laid down in cartilage, then as a preliminary to the formation of adult bone the cartilage is almost entirely removed (Fig. 15 *A*). This is accomplished by an ingrowth from the connective tissue, which surrounds the cartilage and is later to become the periosteum. The ingrowing prolongations (periosteal buds) contain blood vessels and numerous

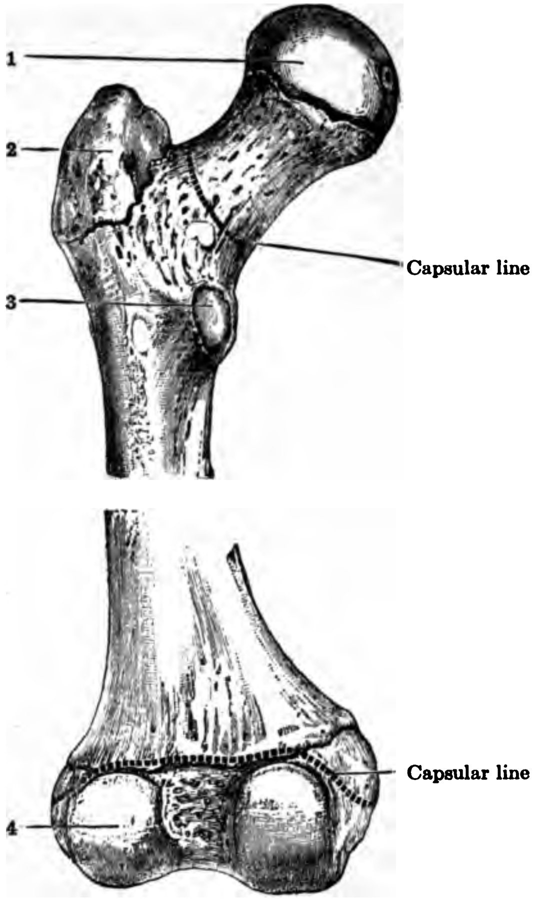


FIG. 15 *B*. — Centers of ossification. Left femur at the twentieth year (posterior view). 1, appears in the first and fuses with the shaft in the twentieth year; 2, appears in the fourth and fuses in the eighteenth; 3, appears in the fourteenth and fuses in the seventeenth; 4, appears in the ninth month of intra-uterine life and fuses in the twenty-first year. The center of ossification of the shaft itself appears in the seventh week of intra-uterine life. (Morris.)

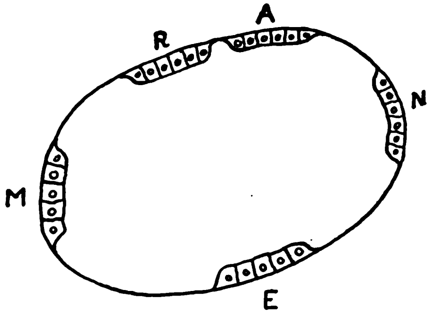
cells called osteoclasts. The latter absorb the cartilage in great part, leaving, however, a few irregular strands. The latter now behave as centers of ossification, and around them the osteoblasts begin to form bone in the manner already described.

The growth of the long bones is of especial interest. The diameter is increased by the deposition of new layers by the osteoblasts beneath the periosteum. The length is increased in the following manner. Some time after the beginning of ossification in the shaft (diaphysis) independent centers of ossification appear in the ends of the bone (epiphyses) (Fig. 15 *B*). As long as the bone is growing the epiphyses and diaphysis remain distinct and between them lies a zone of growing cartilage. When growth ceases, the epiphyses and diaphysis become united by bone and further growth is then impossible.

Muscular and Nervous Tissue. — The muscle cell or muscle fiber is highly endowed with the property of contractility, while the nerve cell or neurone possesses to an especial degree the properties of conductivity and irritability. They are respectively the essential constituents of the muscular and nervous tissue, the properties of which will be referred to in detail later.

Systems. — With the differentiation of function among the cells comes a segregation of the specialized cells into groups or systems, *e.g.* the nutritive group, the excretory group, the locomotor group, and so forth.

The significance of these various systems is grasped most easily if we construct in imagination a complex organism by progressively modifying simpler forms. This may be done very crudely but with accuracy sufficient for our purpose by means of the following diagrams:



FIGS. 16–23. — Diagrams to explain the mutual relations of the various "systems," for alimentation (*A*), respiration (*R*), secretion (*S*), excretion (*E*), motion (*M*), internal transportation (circulation) (*C*), and nervous coördination (*N*). In Fig. 22 the circulation is represented as a current passing by the various cell groups and should be conceived of as giving and taking from each group in turn. Note as a fact (not shown in the figures) that the circulation also serves the nervous system (*N*). In Fig. 23 the connection of the nervous system with all parts of the organism is represented by a few straight lines joining *N* with *R*, *A*, and so forth.

Let Fig. 16 represent an organism of which *A* is a group of cells specialized for the purpose of carrying on the nutritive processes of digestion and absorption. Naturally, the larger the secreting and absorbing surface the more effectively are these processes carried out. Let us, therefore, increase the amount of the surface (Fig. 17). But if only the surface were more protected, the process would be considerably facilitated. Let us, therefore, push in these cells in the direction of the arrows to form a pit or pocket lined with these cells (Fig. 18). It would be an improvement to have two openings into this digestive sack (Fig. 19), which would then become a tube and might be greatly folded so as to increase the active area. Lastly, the secreting surfaces need not be brought into contact with the food; for, provided only their secretion reaches the

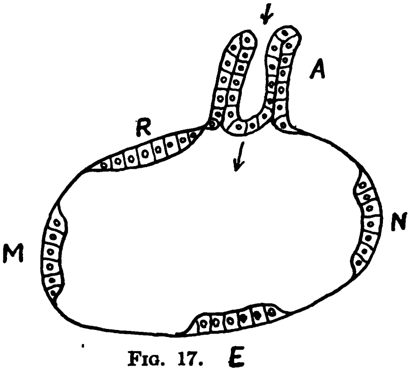


FIG. 17.

food, the result will be all that can be desired. Consequently we may pit in the digestive tube in various places (*e.g.* *S*, Figs. 20, 21) so as to increase our secreting surfaces.

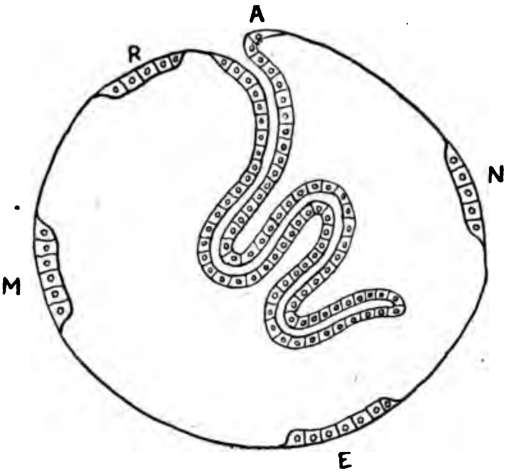


Fig. 18.

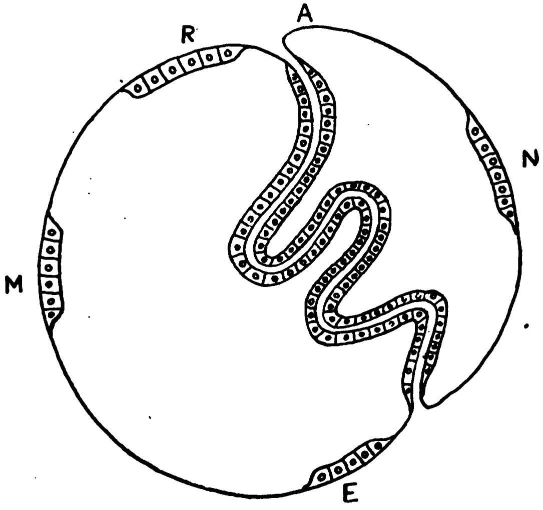


Fig. 19.

But besides the cell group which dissolves solids and absorbs liquids there is a second group which absorbs oxygen and eliminates carbon dioxide (*R*).

The procedure in this case for increasing surface is not carried as far as in the preceding one. Here we stop at the stage (Fig. 21) of pocket formation, albeit a very complex double pocket, the lungs. Here, since there is but one opening to the exterior, the air is alternately sucked in and squeezed out of the single opening.

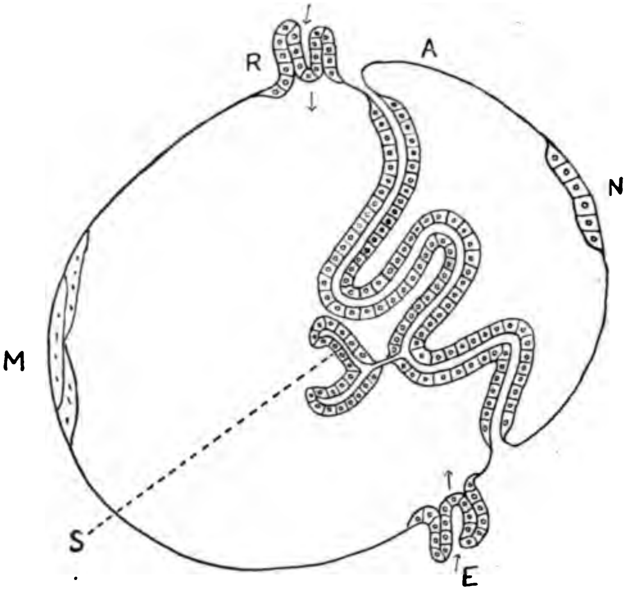


FIG. 20.

The excreting cells *E* may be manipulated in the same way until an arrangement is produced similar to that of the urinary system (Figs. 20, 21).

Next let us add to our organism certain groups of contractile cells which go to make up the voluntary musculature.

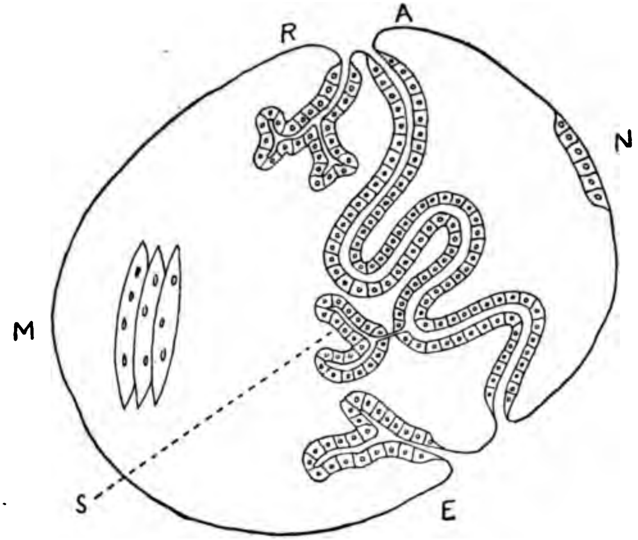


FIG. 21.

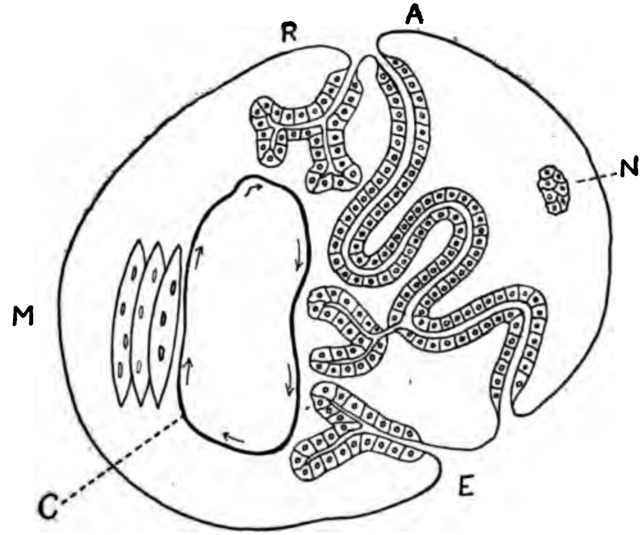


FIG. 22.

D

Now it is easy to see how the cells of *A* obtain their liquid food, but how do they get oxygen? It is easy to see how the cells in *E* can excrete, but whence comes their food? Or, finally, how can the muscle cell get its food or eliminate its waste products?

With specialization of function there comes of necessity an interdependence of the various cell groups and some way must be devised to transfer material from one group to another and for harmonizing the activities of the various groups. This is accomplished by the circulation and the nervous system.

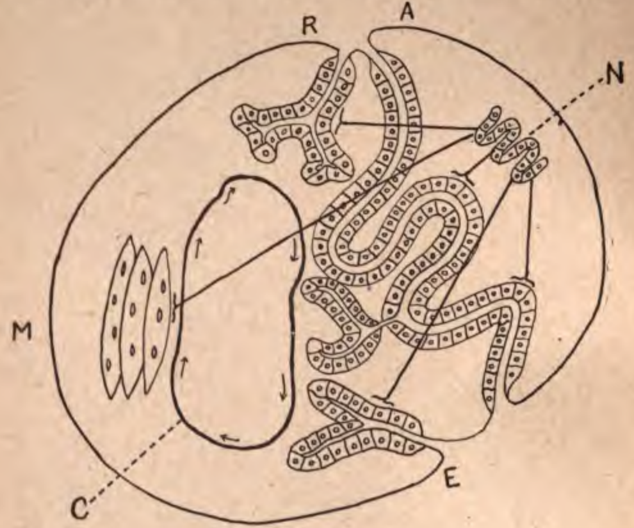


Fig. 23.

The circulation is a stream of fluid which travels, as it were, in a circle, passing each cell group in turn. Into this stream groups *A* and *R* empty their food and oxygen. The stream supplies all the cells of the body with food and oxygen and receives from them their waste products which are removed from the stream by *R* and *E* (Fig. 22).

In this stream also circulate substances (hormones) which help to harmonize the activities of the various organs. But the chief agent for harmonizing or coördinating the activities of the various cell groups is the nervous system, a system of branching cells which are irritable and conducting and carry the effects of stimuli locally applied to all parts of the organism so that it responds as a unit in various appropriate ways (Fig. 23).

CHAPTER III

CONTRACTILE TISSUE

Contractility. — The cells which exhibit the power of contractility to a remarkable degree are the leucocytes (p. 17), the ciliated epithelial cells (Fig. 6), the spermatozoa (p. 255), and the muscle cells.

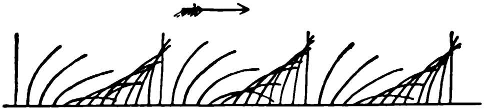


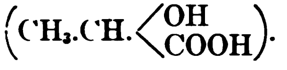
FIG. 24. — Purely diagrammatic representation of ciliary motion. The motion is directed toward the right hand of the figure. Note that the cilia unbend more slowly than they bend.

Cilia. — The ciliated epithelial cells have already been referred to (p. 19). They are principally found lining the respiratory passages. These cells are provided at one end with contractile threads or cilia. In their contraction the cilia curl over suddenly so as to form a hook and then relax more slowly (Fig. 24). This movement is rhythmic and very rapid (twelve contractions a second). Under the microscope a surface covered with actively moving cilia presents a flickering, shimmering appearance not unlike the surface of very rapidly moving water; as the rapidity of motion declines the surface comes to resemble a field of grain over which the wind is causing a succession of waves to pass. By means of this rapid hooking movement small objects lying in contact with the ciliated surface are pushed along. The direction of the ciliary movement is always the same and is independent of the nervous connections of the epithelial cells. The power to conduct from cell to cell is present, for a stimulus applied at one place will set up a change in the ciliary motion which spreads to distant cells. The cilia are killed by heat. Their activity is favored by a slight degree of alkalinity in the liquid covering them. It is by means of cilia that mucus and foreign bodies are swept along toward the exterior of the body. The sweepings of the bronchi, trachea, larynx, and Eustachian tubes pass into the mouth; of the lachrymal duct into the nose and thence to the exterior; of the Fallopian tubes and the uterus to the vagina; of the epididymis and vas deferens into the urethra.

Muscle. — The muscle cells have the power to change their shape so as to become shorter and thicker. They occur in aggregates called muscles, and as the behavior of the muscles is merely a joint effect of the working of all their component cells, the muscles also shorten and thicken when the fibers enter into activity. The shortening is the important part of the process, the thickening is incidental. Through the shortening, the two objects to which the two ends of the muscle are attached are drawn together. This approximation of two points is the essential mechanism of all muscular movement, but, for the present, we are concerned not with the result of such approximation but with the process itself.

Source of Muscular Energy. — The source of the mechanical energy liberated when the muscle contracts is to be looked for in potential energy which is stored in the muscle. As a little heat in the form of a lighted match converts the potential energy of the gunpowder into the mechanical energy of the cannon ball, so the nerve impulse causes a change in muscle which results in the conversion of potential into mechanical energy.

The activity of muscle is associated with the disappearance of glycogen (animal starch), sugar, and perhaps fat and the formation of carbon dioxide (CO_2) and water (H_2O). Consequently we find as the result of muscular exercise an increase of the CO_2 and the H_2O given off from the body. Another product is lactic acid,



$$\left(CH_3.CH.\langle\begin{smallmatrix}OH\\COOH\end{smallmatrix}\right).$$

This substance plays an important rôle in the production of fatigue. After severe exercise it may be found in the urine. Its source and ultimate fate are in great measure obscure.

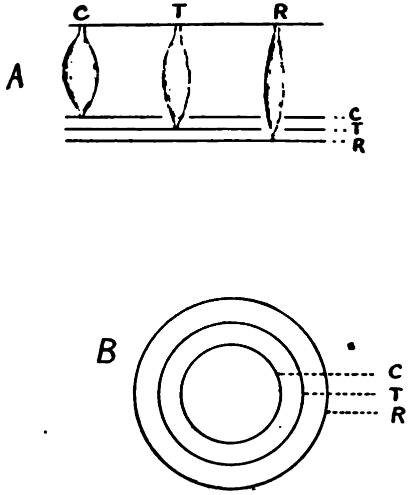


Fig. 25. — Diagrams illustrating contraction, relaxation, and tonus. *A*, a muscle in three states: contraction (*C*), tonus (*T*), and without tonus (*R*, relaxed). The effect of these states upon the length of the muscle is also shown. When the fibers of the muscle are arranged circularly, as in the hollow viscera (heart, uterus, etc.) or the tubular structures (intestine, blood vessels, etc.), the effect of lengthening or shortening is seen in the alteration of the size of the cavity of the viscus and of the caliber of the tubes. This is shown in *B*. When the muscle is contracted, the canal or cavity becomes smaller, and when relaxed, larger.

Tonus. — Ordinarily when we are at rest our muscles are not completely relaxed, but are in a state of subdued but constant contraction known as muscular *tonus* (Fig. 25). Consequently the muscular activity does not begin with the muscle contraction properly so called, but is constantly going on, and what the nerve impulse does is to exaggerate for a time (albeit exaggerate enormously) this condition of tonus. This tonus may be due to one or both of two causes. The first is a peculiarity of the muscle tissue itself which results in what is

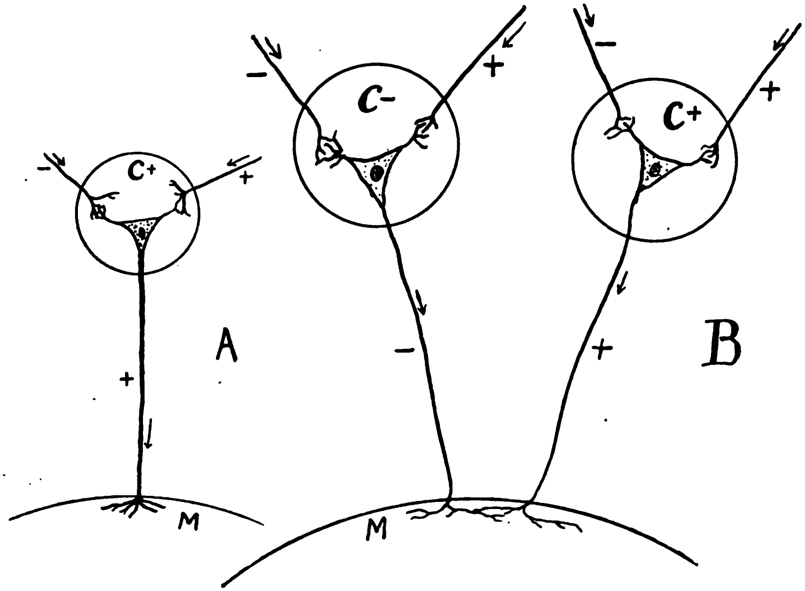


FIG. 26.—Diagram illustrating nervous mechanism of tonus, inhibition, and excitation.

A: striated or voluntary muscle, *M*, has only central tonus, *i.e.* tonus due to impulses which pass to it from a nerve center, *C*, which excite it. Nerve impulses which come to this center may either excite it (+), thereby causing an increase in the tonus of the center and consequently of the muscle, or they may inhibit (−) the tonus of the center, thereby causing a decrease in the tonus of the muscle.

B: plain muscle and cardiac muscle have both central and peripheral tonus, the latter being a property of the muscle itself. Its peripheral tonus cannot be abolished by separating it from the center, *C*+; this can be accomplished only by the activity of a second center, *C*−, which inhibits the muscle. These two centers are in tonic activity, but their tonus can be increased or decreased by impulses coming to them. We may therefore decrease the tonus of *M* by inhibiting *C*+ or by exciting *C*−, and we may increase the tonus of *M* either by exciting *C*+ or by inhibiting *C*−.

Of the three nerve centers figured, two are excitatory and one inhibitory and all three are in tonic activity, *i.e.* continuously sending in weak impulses to the muscles. Of the two muscles, one (*A*) possesses only central tonus, but the other (*B*) both central and peripheral tonus.

known as "peripheral" tonus; the second consists in an inflow of stimuli along the nerves with which the muscle is supplied and results in "central tonus." In other words, muscular tonus may be of muscular (*e.g.* in plain muscle of which the nerves have been cut) or of nervous origin (*e.g.* in striated muscle) or of both (*e.g.* in plain and cardiac muscle). Wherever there is muscular tonus there is also the possibility of abolishing this tonus, in other words, of causing a relaxation which is greater than normal.

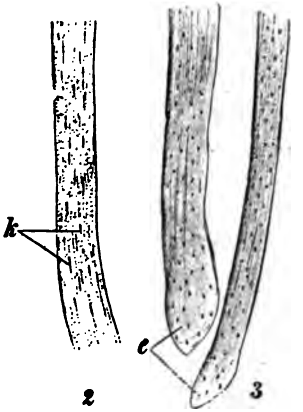


FIG. 27. — Striated muscle fibers. *k*, normal nuclei; *e*, nuclei made more distinct by treatment with alkali. At this magnification the cross striations are not visible. (Stoehr.)

Excitation and Inhibition. — Besides the nerves whose function it is to cause organs to become active and which are called *excitatory* there are those which have the reverse effect and are called *inhibitory*. It is by means of the latter that tonus, whether central or peripheral, is at times abolished. These facts are illustrated in the accompanying diagram (Fig. 26), where the sign + is used to indicate an excitatory action, – an inhibitory action. To this subject we shall return again (p. 89).

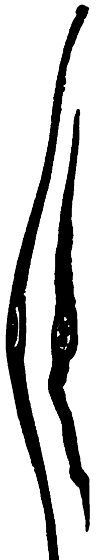


FIG. 28. — Plain muscle fibers from the small intestine. (Stoehr.)

There are three kinds of muscle cells, (Figs. 27–29), striated, plain, and cardiac, which we shall consider in the order mentioned.

Striated Muscle. Methods of Study. — For the study of the contractions of this sort of muscle (Fig. 27) two methods are used, the myographic and the ergographic. In the first of these a contracting muscle is caused to write upon a very rapidly moving surface (Fig. 30), so that not only the height of the contraction but its duration and other time relations can be determined. In such a myogram (Fig. 31) the following points are noteworthy: (1) the very brief latent period (period between

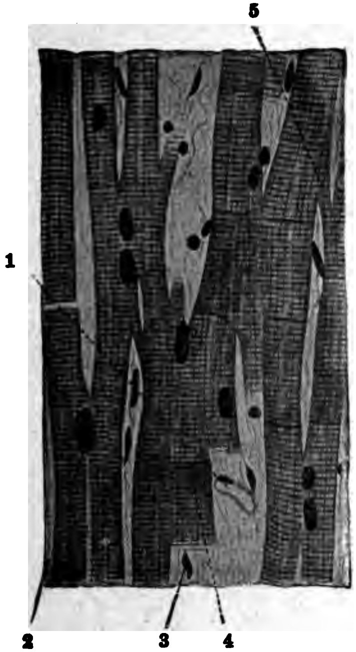


Fig. 29. — Heart muscle. Longitudinal section of a human papillary muscle. 1, capillary; 2, nucleus of a muscle fiber; 3, nucleus of a connective tissue cell; 4, intercalated disk; 5, lateral union. (Stoehr.)

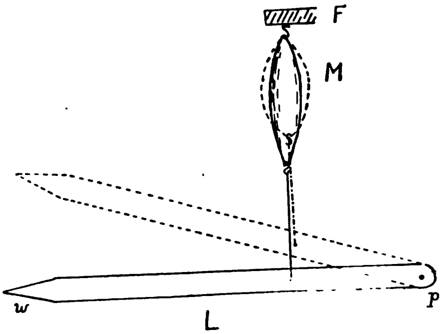


Fig. 30. — Diagram illustrating the mode of obtaining the curve of contraction of a muscle. A muscle (M) is attached at one end to a fixed point (F) and at the other to a movable lever (L). The lever is pivoted at p, while the other end of the lever is made into a writing point (w). When M contracts, it elevates L (shown by dotted lines). w can be made to write upon a surface. If the surface be stationary, w will write a nearly vertical up-stroke and, when the muscle relaxes, return to the place whence it started, but if the surface be moving, it will write a curve similar to that shown in Fig. 31.

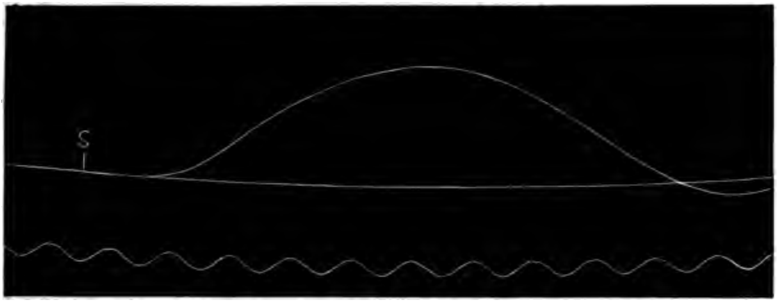


FIG. 31. — Curve of muscle contraction. At *S* the stimulus was applied, and the time which elapsed between *S* and the beginning of the contraction is the latent period. Below the muscle curve is a wavy line traced by a chronometer; the period from crest to crest is 0.01 sec. (Howell.)

the movement of stimulation and that of contraction), (2) the rapid contraction, and (3) the rapid relaxation. The advantage of a brief latent period, a rapid contraction and relaxation, and a duration of contraction which can be controlled at will is obvious. In the second, or ergographic, method (Fig. 32) the contraction of the muscle is recorded

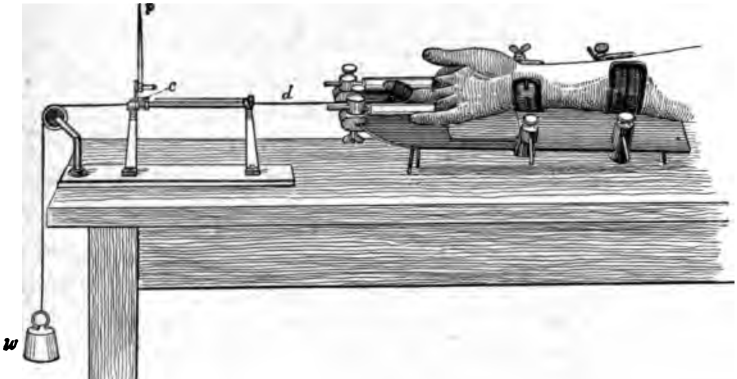


FIG. 32. — Ergograph. *c*, the carriage moving to and fro on runners by means of the cord, *d*, which passes from the carriage to the holder attached to the last two phalanges of the middle finger (the adjoining fingers are held in place by clamps); *p*, the writing point of the carriage, *c*, which marks the record of its movements on a slowly moving surface; *w*, the weight to be lifted. (Howell.)

upon a slowly moving surface. In this way we obtain not curves but straight lines, so that only the extent of contraction can be determined by this method (cf. Figs. 33, 35, 36, and Figs. 31, 37).

Effect of Load. — If we cause a muscle to give a short series of contractions such that with each contraction a weight is lifted and arrange our experiment in such a manner that with each contraction the weight lifted is heavier than the one which preceded it, we shall find, as seems natural, that the extent of the contraction gradually becomes less until the weight can no longer be lifted at all (Fig. 33). If we determine the amount of work performed by each contraction (work = height to which the weight is raised × the amount of the weight), it is found that the amount of work is for a time increased. Later, of course, it decreases until zero is reached, but it is interesting to observe that for the greatest efficiency, *i.e.* the greatest amount of work per contraction, there is an optimum weight and all other weights are more or less too light or too heavy (Fig. 34).

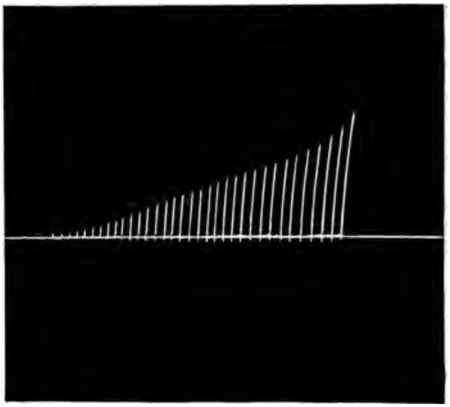


FIG. 33. — Effect of increasing load on the extent of contraction of the gastrocnemius muscle of a frog. In the first contraction (to the right) the load was 14.2 grams; at each successive contraction the weight was increased by 5.3 grams until a total load of 182 grams was reached, when the muscle ceased to give a measurable contraction. (Howell.)

Fatigue. — If we cause a muscle to contract repeatedly at equal intervals of time and thereby to lift a constant weight, the extent of the contraction soon begins to show a decrease until finally the weight can no longer be raised (Fig. 35). This loss of muscular power is known as *fatigue*. Every individual has for any particular time a "fatigue curve" of his own. With improvement in the health comes a delay in the appearance of fatigue. Worry and intellectual work hasten the onset of fatigue.

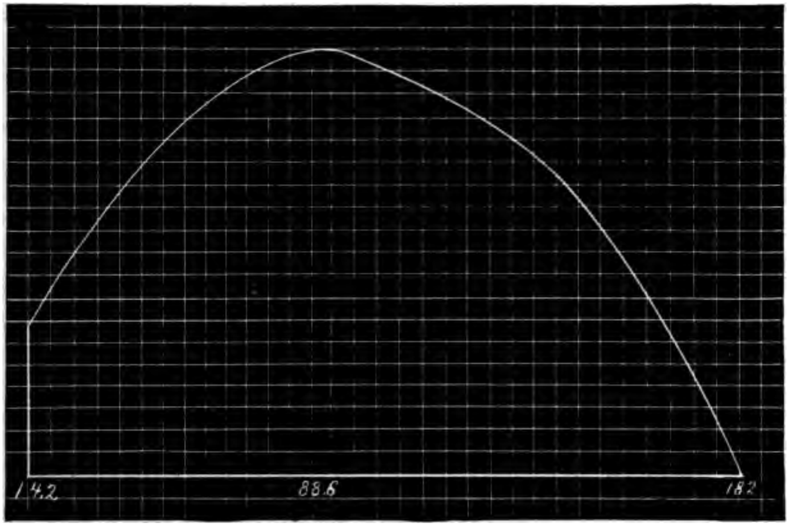


FIG. 34. — Curve of work obtained by plotting the results shown in the previous figure. The initial contraction did an amount of work represented by the height of the curve above the base line. The amount of work (height lifted multiplied by the weight lifted) increased with the increase of the load until a maximum was reached with a load of 88.6 grams. The amount of work per contraction then decreased until with 182 grams the muscle failed to contract and the work per contraction became zero. (Howell.)

The contractions in different parts of a series do not produce fatigue to the same extent; the later contractions are more fatiguing than those which occurred earlier. If, for example, thirty contractions are required to produce complete exhaustion which may be recovered from only after a rest of two hours, then the time required for recovery from the effect of fifteen contractions is only half an hour.

“**Fatigue Substances.**” — It has been stated that among the products of muscular activity are carbon dioxide (CO_2) and lactic acid $\left(CH_3.CH.\begin{matrix}\diagup OH\\ \diagdown CO_2H\end{matrix}\right)$. These substances are gradually removed by the blood stream, and if they accumulate in the muscle, they act as poisons to the muscular tissue, causing a decrease in irritability. This constitutes the condition we call fatigue, and consequently the substances in question are known as fatigue-producing or simply as fatigue substances. It has been shown very impressively that the injection of the extract of fatigued muscle into the veins of a sprightly animal will promptly bring on signs of fatigue. It is therefore easy to understand how it happens that the use of one set of muscles (*e.g.* those of the legs) causes signs of fatigue in quite another set (*e.g.* those of the arms), for the fatigue substances circulate for a time in the blood and

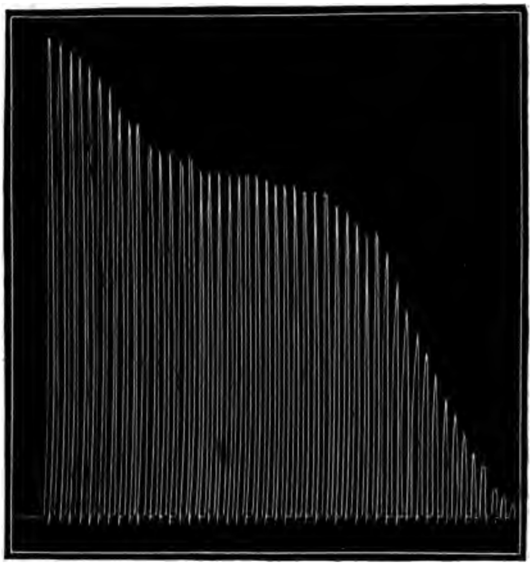


FIG. 35. — Normal fatigue curve of the flexors of the middle finger of the right hand. Weight 3 kilos, contraction at intervals of two seconds. (Maggiora.)

lead to a greater or less decrease of muscular irritability until they are further oxidized and eliminated from the body.

Fatigue Level. — In every series of muscular contractions there are three possible variables: (1) the extent of contraction, (2) the rate of contraction, and (3) the amount of weight lifted. If two of these are fixed, the third can be so chosen that fatigue will not develop. For, since fatigue is due to the accumulation of waste products, it is only necessary to keep the rate of production of these substances from rising above the rate of their elimination, as is made clear by the accompanying ergograms. In the first of these (Fig. 36 *A*) the subject contracted the middle finger every two seconds, thereby lifting a weight of two kilos. At 1 the weight was reduced to one kilo and at 2 to 500 grams. Here we see that the weights of 1 and 2 kilos caused a formation of waste prod-

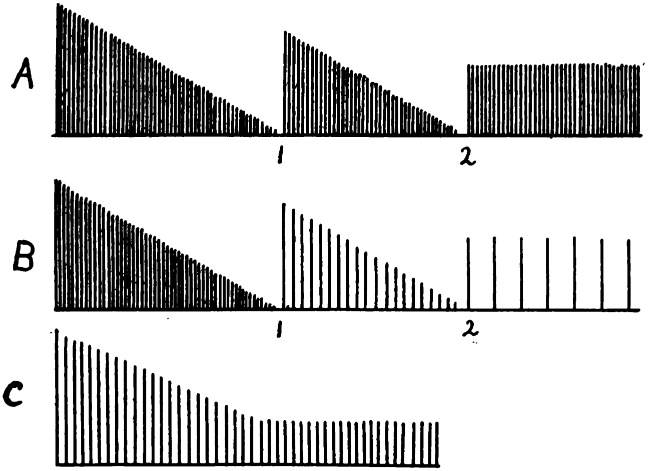


Fig. 36. — Diagrams representing ergographic records. They show the "fatigue level" and are explained in the text.

ucts which was more rapid than their elimination, but that with 500 grams this was not the case. In *B* the subject began to contract as before, but at 1 the rate of contraction was changed from once in 2 seconds to once in 4 seconds and at 2 to once in 6 seconds. Here we see that with rates of once in 2 and once in 4 seconds the production of fatigue substances was more rapid than their elimination, but that with a rate of once in 6 seconds this was not the case. The subject was not, of course, completely exhausted at either 1 or 2 but merely unable to lift so great a weight at 1 kilo in one case and 2 kilos in the other. In *C* the weight is between 500 grams and 1 kilo. At first the curve falls, but soon it ceases to do so. Here without decreasing the weight or increasing the rest between contractions a decrease in the extent of the contraction was of itself enough to reduce the rate of production of waste products to or below the rate of their removal.

From these considerations it is easy to see why we can do light work with great speed but must do heavy work slowly, and also how it is that if we begin too energetically, we soon " let up," gradually " striking a pace " (reaching a " fatigue level ") at which we can continue our labor for a very long time.

Plain Muscle. — The second kind of muscle (Fig. 28) is not under the control of the will and consequently often called " involuntary " muscle. It occurs in the walls of the arteries, veins, alimentary canal, genital and urinary organs, bronchi, etc. This muscle differs from the striated variety in a number of particulars. Its myogram (Fig. 37) shows that its time relations are very different from those of striated muscle. Its latent period is long, its contraction leisurely, and its relaxation slow. As already stated, it possesses peripheral tonus to a marked degree. Moreover, it at the same time shows rhythmic contractions which may be independent of the nervous connections and are therefore a property of the muscle itself (*e.g.* ureters).

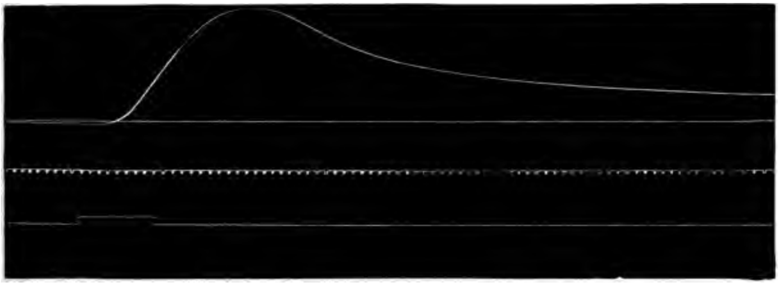


Fig. 37. — Myogram of plain muscle contraction. The middle line is made by a chronograph marking seconds. The lowest line indicates at the break the beginning and end of the period of stimulation. Here the latent period is seen to be about three seconds. (Howell.)

Cardiac Muscle. — Of the properties of cardiac muscle little will be said at this time (see p. 151). It is characterized by automatic, rhythmic contraction. In its latent period, contraction, and relaxation it lies intermediately between striated and plain muscle. Its tonus is peripheral in origin and possibly central also (see Fig. 26).

CHAPTER IV

ANIMAL MECHANICS

From the point of view of physiology the skeleton and musculature constitute merely a system of levers and an aggregation of points which may be separated or brought together by means of muscular contractions. The underlying principle is therefore extremely simple. All the rest is mechanical detail of some practical but of little fundamental importance. But to the nurse the skeleton and musculature are, at present, an exceptionally important part of the human body, for they are almost the only internal structures with which she is likely to have a first-hand acquaintance. It should never be forgotten that each pupil carries about with her a skeleton and musculature of her own. The former should be palpated and compared with dried specimens, while the latter should be studied during rest and activity and the larger muscular masses identified by reference to suitable illustrations.

The Skeleton. — The general arrangement of the bones of the skeleton is shown in Fig. 38 and the names of the principal bones are given in the legend.

The Skull. — The bones of the skull are sometimes divided into two groups, first, the bones of the cranium, the case which surrounds the brain, and secondly, the bones of the face. In studying the skull let us examine with care and discuss Figs. 39–42 *B*. Fig. 39, the skull in right semi-profile, shows at 1 the junction of the frontal, ethmoid, and lachrymal bones. The lachrymal bone, that

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to the right and below in the picture, forms with the maxillary bone at their juncture the orifice of the nasal duct for the passage of the tears from the surface of the eye into the nasal cavity. 2, Prominent portion (tuber) of the frontal bone; 3, superciliary arch of the frontal bone; 4, supra-orbital foramen or notch which transmits part of the first branch of the trigeminal nerve which constitutes the sensory supply to the forehead; 5, depression

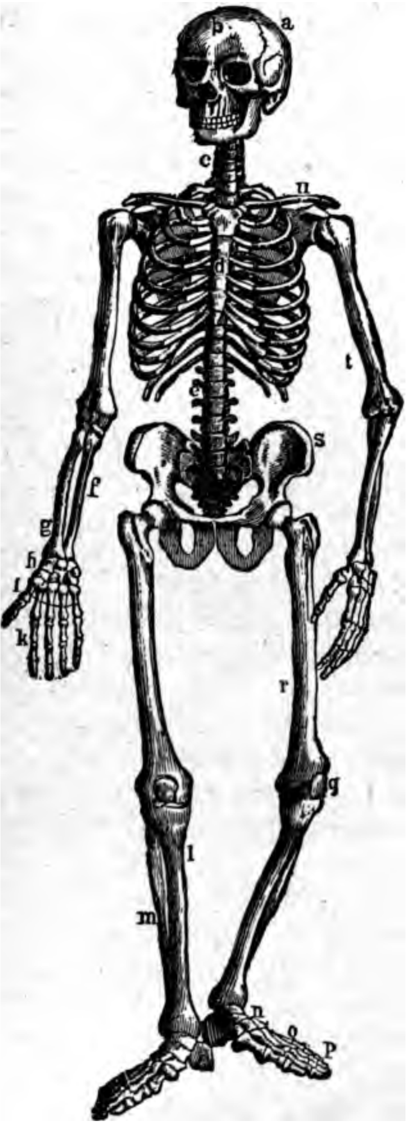


Fig. 38.—The skeleton. *a*, occipital bone; *b*, frontal bone; *c*, the vertebræ of the cervical region; *d*, sternum (breast bone) on either side of which are the ribs; *e*, vertebræ of the lumbar region. The vertebræ to which the ribs are attached are known as the thoracic vertebræ. *f*, ulna; *g*, radius; *h*, eight bones composing the carpus; *i*, five metacarpal bones; *k*, phalanges of the fingers; *l*, tibia; *m*, fibula; *n*, seven bones composing the tarsus; *o*, five metatarsal bones; *p*, phalanges of the toes; *q*, patella (knee cap); *r*, femur (thigh bone); *s*, os coxæ, composed of three bones fused together, the ilium, adjacent to the letter *s*, the pubis, uniting in front with its fellow of the opposite side, the ischium, seen in the figure as the lowermost part of the bone. Between the ilia and below the lowest vertebra is the wedge-shaped sacrum. (Kimber.)

for the lachrymal gland which secretes the tears; 6, infra-orbital fissure between the sphenoid and maxillary bones, the latter being in front. Within the body of the maxillary bone is a cavity or sinus communicating with the nasal cavity; 7, infra-orbital foramen, which transmits a part of the second branch of the trigeminal nerve to supply the face with sensory fibers; 8, anterior nasal spine. Above and behind this lies the nasal cavity. In it the vomer and the vertical plate of the ethmoid can be dimly seen and to the right of them the left nasal concha ("lower turbinated bone"). The septum, which divides

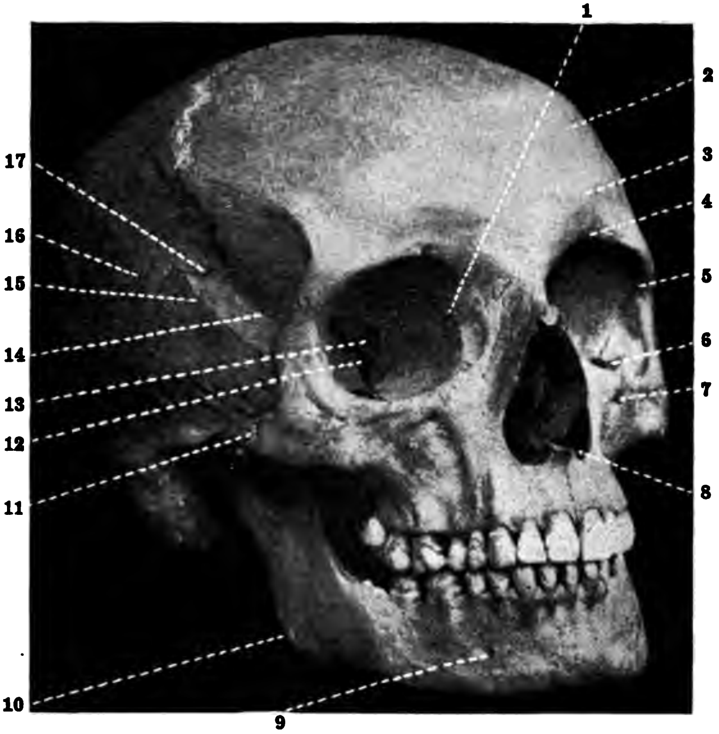


FIG. 39. — The skull, right semiprofile. (Cleland and MacKay.)

the nasal cavity into two parts, is formed by the vomer and the vertical plate of the ethmoid behind, and by a vertical plate of cartilage in front. Higher up in the cavity, on either side of the vertical plate of the ethmoid, are the "upper and middle turbinated bones" (not seen in the picture). These are parts of the ethmoid and not separate bones as are the conchæ; 9, foramen for the passage of a part of the third branch of the trigeminal nerve supplying sensory fibers to the lower jaw (mandibula); 10, angle of the jaw; 11, suture between the zygomatic process of the temporal bone and the zygomatic bone; 12, fissure in the sphenoid, which transmits part of the first branch of the trigeminal nerve, the oculomotor and the abducens nerve; 13, optic foramen, which transmits the optic nerve carrying impulses from the eye to the brain; 14, great wing of the sphenoid bone; 15, suture between the great wing of the sphenoid bone and the squamous portion of the temporal bone; 16, suture between the squamous part of the temporal bone and the parietal bone; 17, suture between the parietal and sphenoidal bones.

Fig. 40, the right lateral aspect of the skull, shows at 1, the protuberance of the frontal bone; 2, superciliary arch of the frontal bone; 3, infra-orbital fissure; 4, zygoma or yoke under which passes the temporal muscle (see Fig. 52) and to the anterior part of the lower and inner aspect of which is attached the masseter muscle; 5, part of the sphenoid bone; 6, styloid process of the temporal bone. To the left lies the mastoid process of the temporal bone, which affords attachment to the sterno-cleido-mastoid muscle. The other end of the muscle is attached by two heads to the sternum and the inner one third of the clavicle. Its action is to depress and rotate the head and also, when the head is held rigid and both muscles contract in unison, to elevate the chest.

(See Fig. 48, No. 18, and Fig. 54, No. 3.) 7, external occipital protuberance which affords attachment to the ligament of the nape of the neck (ligamentum nuchæ), which arising from the cervical vertebræ and being inserted into the occipital bone helps to support the head like an elastic check rein when the head is inclined forward; 8, line of attachment of the trapezius muscle; 9, meeting of the sagittal suture (between the parietal bones) and the lambdoid suture (between the occipital and the two parietal bones).

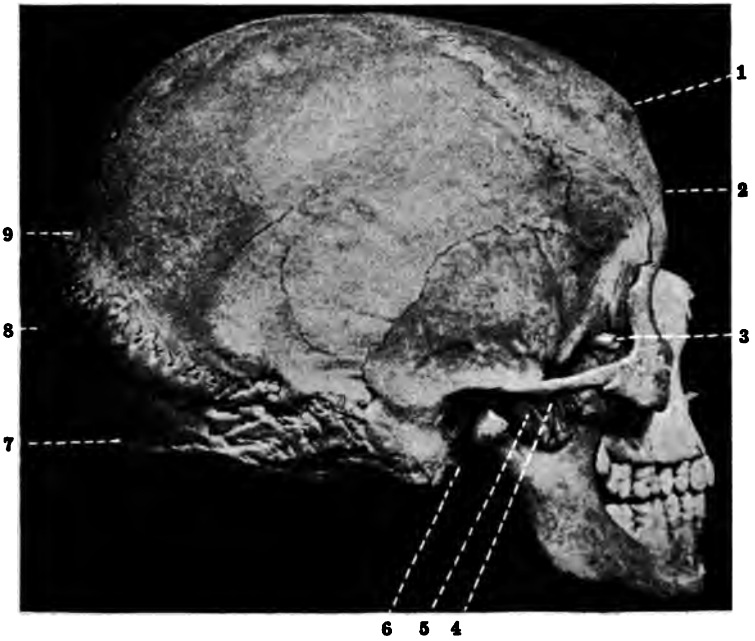


FIG. 40. — The skull, right lateral aspect. (Cleland and MacKay.)

Figure 41 shows a sagittal section of the skull cut slightly to the right of the middle line. Passing from above downward the line 1–5 crosses the outer and inner tables of the parietal bone, the spreading branches of grooves in which rest during life one of the arteries (meningeal) supplying the membranes which envelop the brain (meninges); at the lower end and to the left is the internal acoustic meatus, for transmission of the acoustic nerve. Line 2–6 passes over the frontal sinus (a cavity containing air and communicating with the nasal cavity), the frontal, sphenoid, temporal, parietal, and occipital bones to the external occipital protuberance. The point at which lines 3 and 4 meet lies at the junction between the ethmoid and sphenoid bones. The line from this point to 5 passes across the sphenoidal sinus, the sphenoid and the occipital bones. The line 3

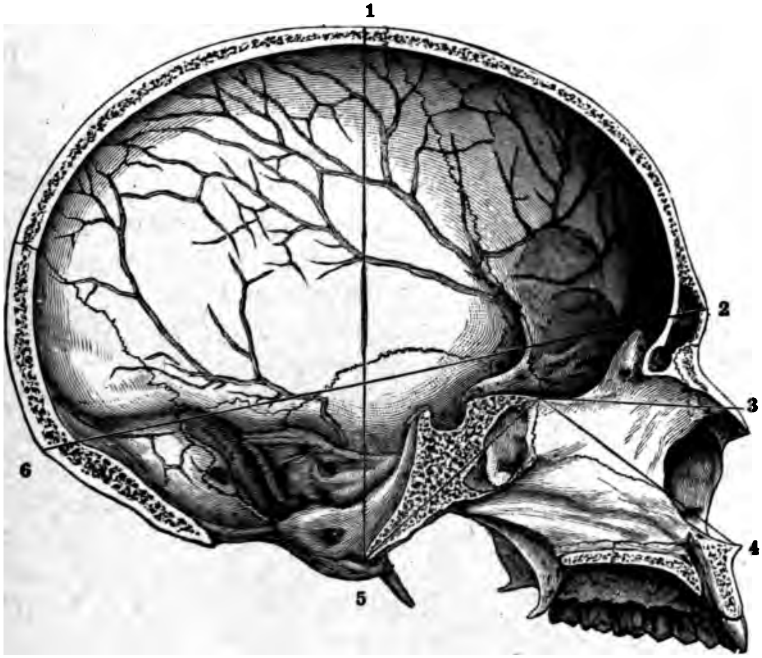


Fig. 41.—Sagittal section of the skull, cut slightly to the right of the middle line. (Morris.)

crosses the nasal and ethmoid bones; the line 4 touches the junction between the vomer and the ethmoid.

Figure 43 *A*, the base of the skull from below, shows at *a*, the infra-orbital fissure with the roof of the orbit to be seen through it; *b*, a part of the ethmoid bone, between which and the corresponding point of the opposite side is seen the posterior nasal opening; *c*, vomer and palate bones in contact; *d*, cavity for articulation with the lower jaw; *e*, foramen for the transmission of the internal carotid artery, which with the vertebral artery furnishes the blood supply to the brain; *f*, a part of the sphenoid

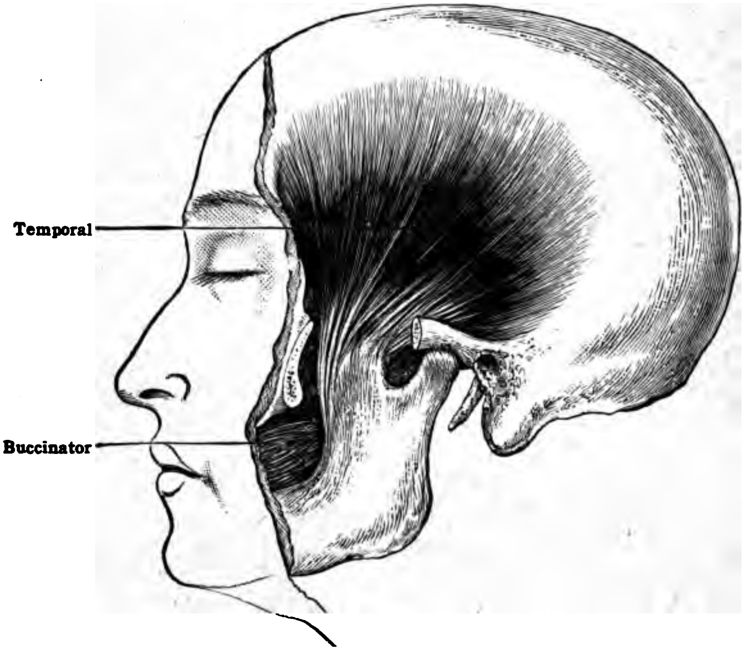


FIG. 42. — Origin and insertion of the temporal and buccinator muscles. The former is a biting muscle. The latter takes its origin from the maxillary bone and the mesial aspect of the mandible and is inserted into the orbicularis oris (a circular muscle surrounding the mouth). The action of the buccinator is to draw the cheeks in and in this way it aids the tongue in moving and holding the food during mastication. (Morris.)

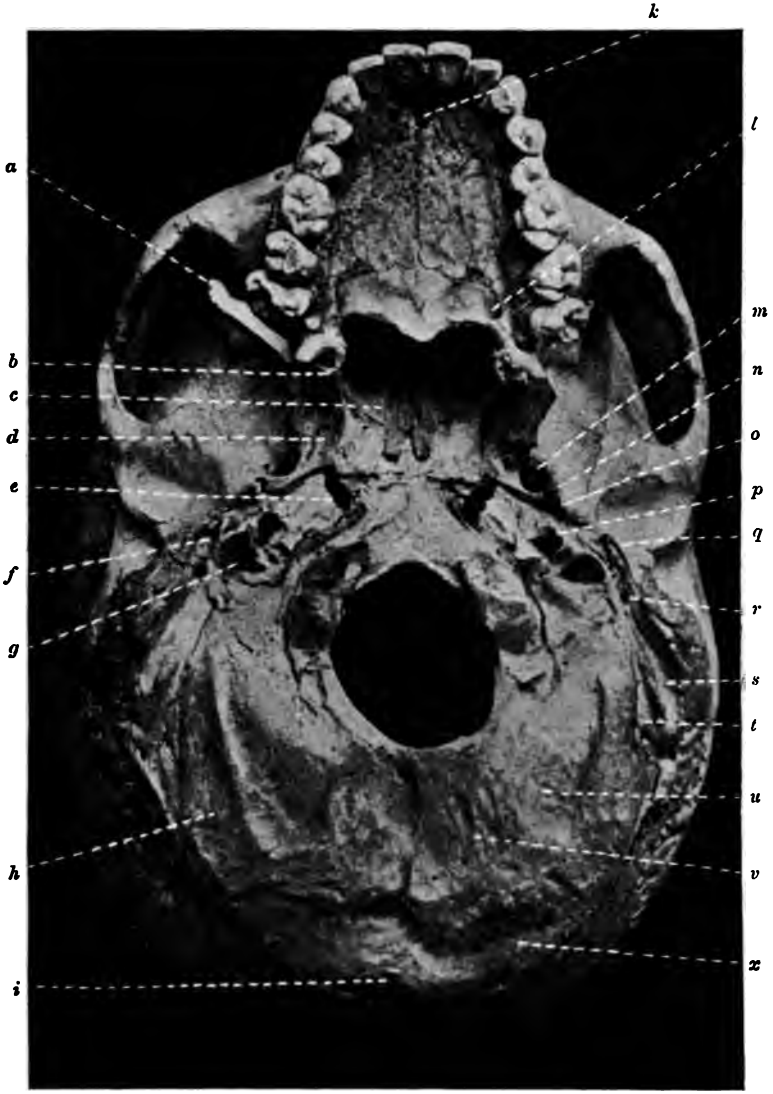


FIG. 43 *A*. — Base of the skull from below. (Cleland and MacKay.)

bone; *g*, foramen for the transmission of the glossopharyngeal, vagus and accessory nerves and the internal jugular vein which carries off the venous blood from the brain; *h*, roughened areas for the attachment of the neck muscles; *i*, external occipital protuberance; *k* and *l*, canals for the transmission of nerves to the roof of the mouth and so forth; *m*, foramen ovale, which transmits the third branch of the trigeminal nerve; *n*, foramen spinosum for the middle meningeal artery; *o*, groove for the auditory (Eustachian) tube; *p*, carotid canal, which transmits the internal carotid artery; *q*, styloid process of the temporal bone; *r*, stylo-mastoid foramen through which the facial nerve emerges from the temporal bone; *s*, mastoid notch; *t*, occipital groove; *u*, *v*, *x*, rough areas for the attachment of the neck muscles.

Figure 43 *B*, the base of the skull from above, shows at 1 and 2, the frontal bone; 3, the "Cock's comb" (ethmoid); 4, anterior fossa of the cranial cavity; 5, perforations (cribriform plate) of the ethmoid bone for transmission of the olfactory filaments; 6, small wing of the sphenoid; 7, groove for the optic chiasma; 8, depression for the lodgment of the hypophysis cerebri; 9, sphenoid bone; 10, junction of the sphenoid and temporal bones. In this region upon the temporal bone near its pointed end toward the midline on its superior surface is a depression for the lodgment of the semilunar (Gasserian) ganglion of the trigeminal nerve. Posterior and lateral to this is a large opening into the temporal bone (internal acoustic meatus) by which the facial and acoustic nerves enter the temporal bone. The former emerges again by the foramen spinosum and passes to the muscles of the face; the two branches of the latter end in the cochlea and the semicircular canals of the internal ear, respectively; 11, middle cranial fossa; 12, occipital bone, upon

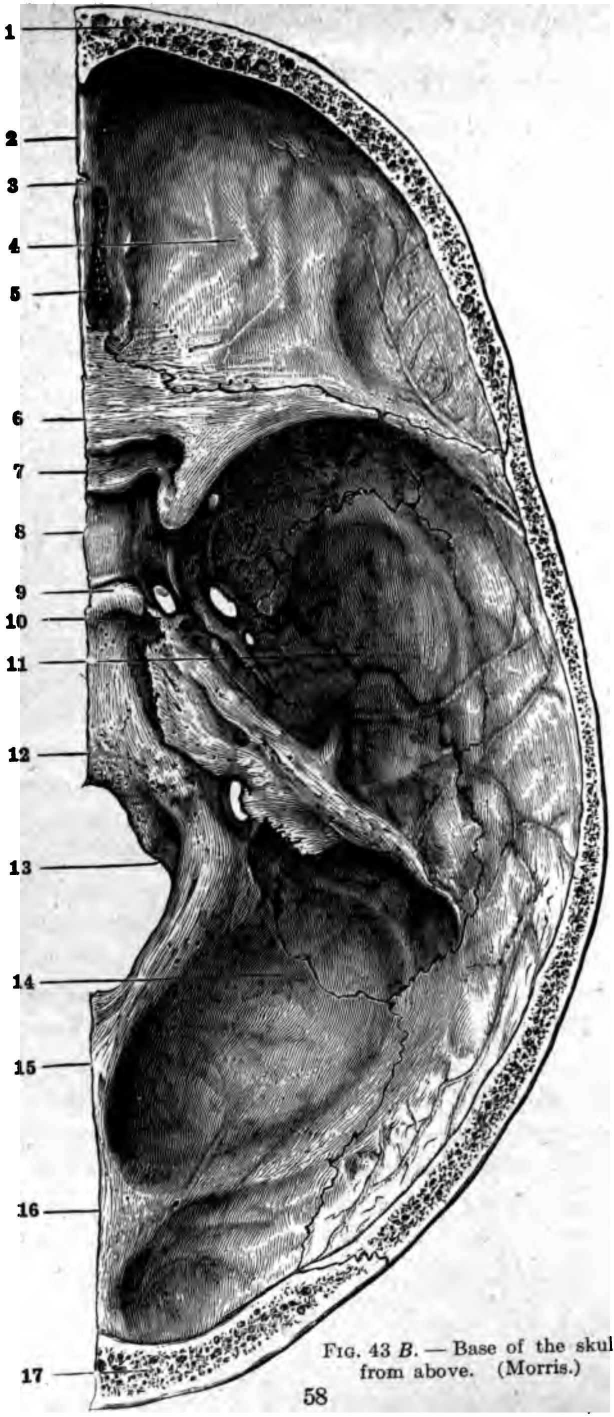


FIG. 43 *B*. — Base of the skull from above. (Morris.)

which in this region rests the medulla oblongata; 13, foramen magnum, through which pass the spinal cord, the vertebral arteries (which with the two internal carotids constitute the blood supply of the brain), and lastly the spinal part of the accessory nerves which enter the cranium through this passage to emerge again in company with the vagus through the jugular foramen; 14, posterior cranial fossa; 15, occipital bone; 16, internal occipital protuberance; 17, spongy part of the occipital bone (diploë) between its outer and inner tables.

At birth the bones of the cranium do not meet to form a rigid case and the spaces between the bones are called fontanelles. Here the brain is covered only with soft tissues so that the pulsations of the arteries of the brain may be felt or even seen. At this time also the frontal bone is divided into right and left halves which later become fused into a single bone. Under normal conditions the fontanelles close at about the second year. (See Fig. 45.)

The Hyoid Bone. — The hyoid bone (Fig. 44) may be felt just above the larynx. It does not articulate with any other bone but affords attachments for several muscles which move the tongue, jaw and adjacent parts.

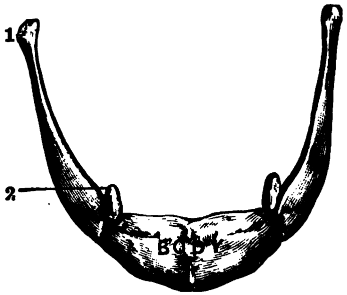


Fig. 44. — Hyoid bone. The convexity is directed forward. 1, greater cornu; 2, lesser cornu. (Morris.)

The Vertebræ. — The vertebral column is shown in Fig. 46. It is made up as follows: cervical vertebræ 7, thoracic 12 (each bearing a pair of ribs), lumbar 5, sacral 5 (fused together to form the sacral bone), coccygeal vertebræ 4 (fused together to form the coccyx).

Viewed from the side the vertebral column is seen to

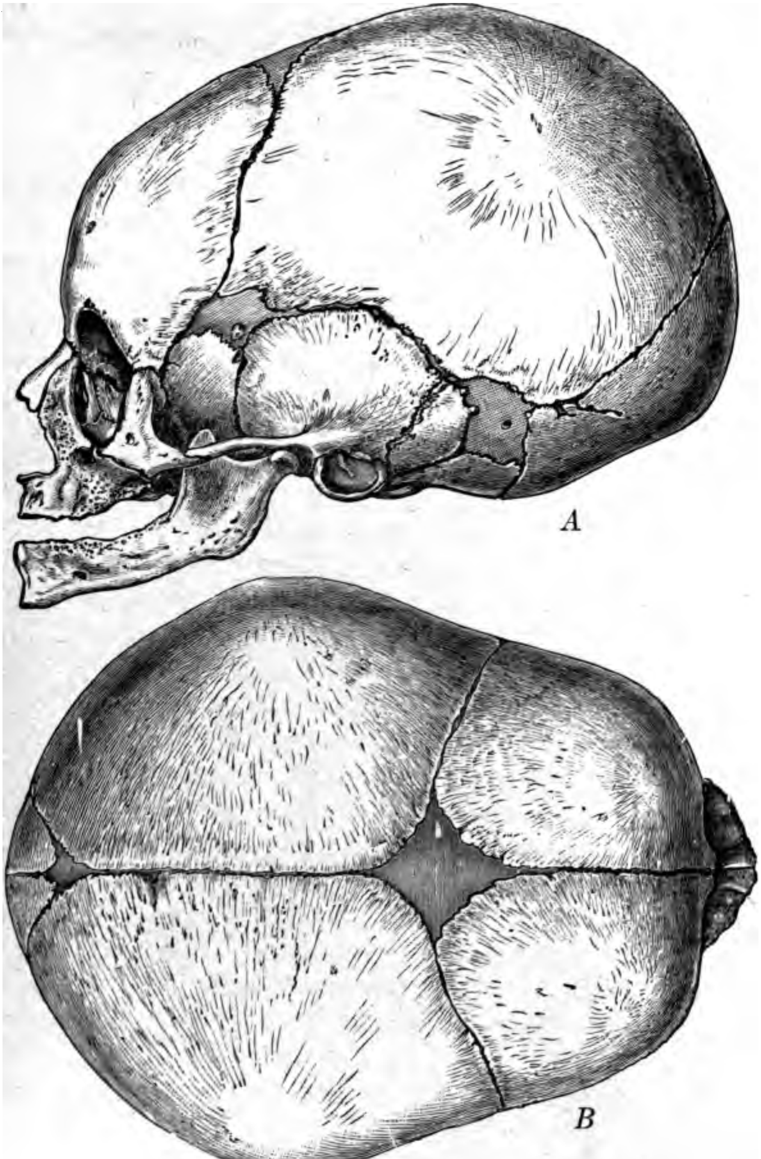
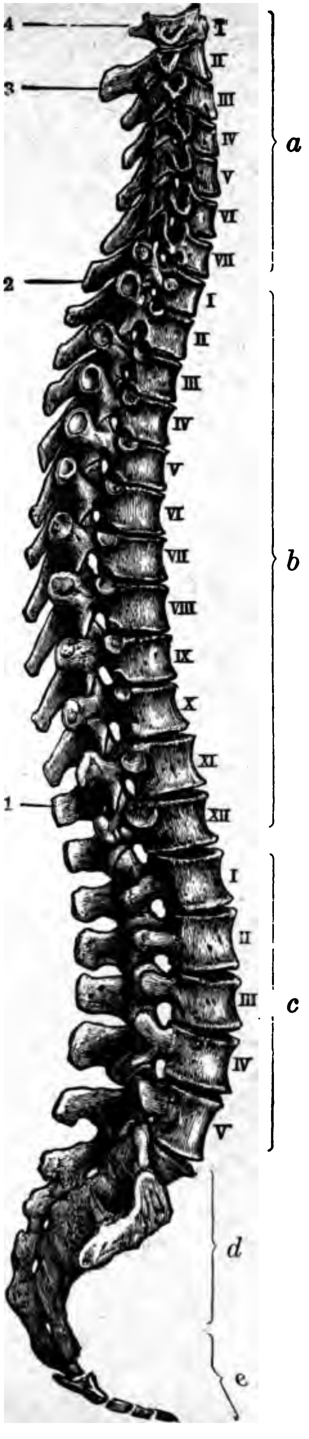


FIG. 45. — Fontanelles in the skull of the new born. *A*, fonticulus occipitalis; f. frontalis; f. sphenoidalis, and f. mastoideus. *B*, fonticulus occipitalis and f. frontalis. (Morris.)

FIG. 46. — The spine. Lateral view. *a*, cervical; *b*, thoracic; *c*, lumbar; *d*, sacral; *e*, coccygeal vertebræ; 1, 11th thoracic or anticlinal vertebra; 2, vertebra prominens; 3, epistropheus (axis); 4, atlas. (Morris.)



have two convexities directed ventrally and one dorsally. The former are in the cervical and lumbar regions respectively, the latter is present in the thoracic region.

The vertebræ differ in different parts of the spinal column, but the form present in the thoracic region may be taken as typical (Fig. 47). The vertebra possesses a body, arch and processes. The body serves as a support, the arch incloses the spinal cord and the processes afford attachment for muscles. The processes are divided into the dorsal or spinal process and the lateral or transverse processes. Between the bodies of the vertebræ are disks of fibro-cartilage which act as cushions to diminish the jar of the column. Between each pair of vertebræ there are two foramina (intervertebral) formed by the intervertebral notches above and the basal parts of the vertebral arches below. These foramina transmit the spinal nerves passing from the cord to be distributed throughout the body. Numerous muscles are attached to the vertebræ. The deeper layers run longitudinally from one region of the vertebral column to another and unite the whole along its dorsal aspect. Their action is to

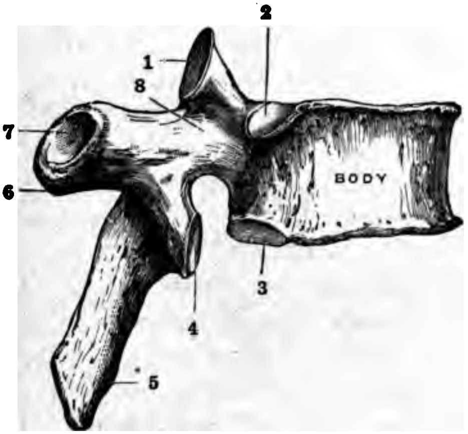


FIG. 47. — Thoracic vertebra. 1, superior articular process; 2, superior costal depression; 3, inferior costal depression; 4, inferior articular process; 5, spinous process; 6, transverse process; 7, costal depression of transverse process; 8, root of vertebral arch. (Morris.)

bend the column backward and to give support in maintaining the column in any desired position.

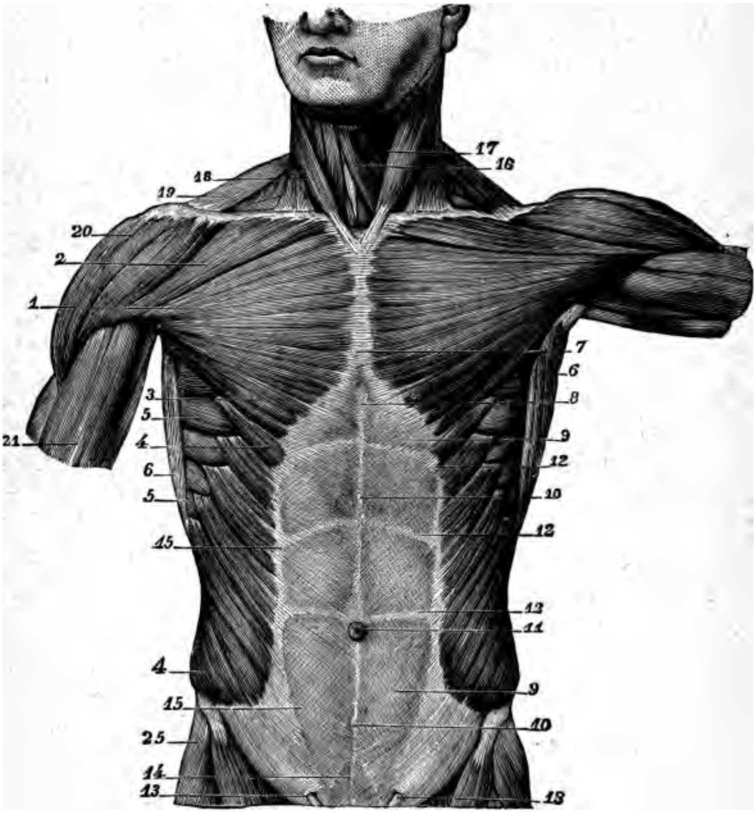


FIG. 48. — Anterior surface of the abdominal wall. 1, 2, 3, 7, pectoralis major; 4, external oblique; 5, serratus anterior; 6, latissimus dorsi; 8, lower end of sternum; 9, 15, aponeurosis of external oblique; 10, 14, linea alba; 11, umbilicus; 12, transverse lines of the aponeurosis; 13, the spermatic cord emerging from the cutaneous abdominal ring; 18, sterno-cleido-mastoid; 19, trapezius; 20, deltoid; the lower border of the aponeurosis of the external oblique forms the inguinal (Poupart's) ligament. (Gould.)

Certain other superficial muscles which are also attached to the vertebræ, are of especial interest, namely, the trapezius (see scapula), psoas major (see femur), the diaphragm (see ribs). The first and second cervical vertebræ (Fig. 49) are sufficiently peculiar to merit special names. The first, the atlas, is ring shaped and articulates above

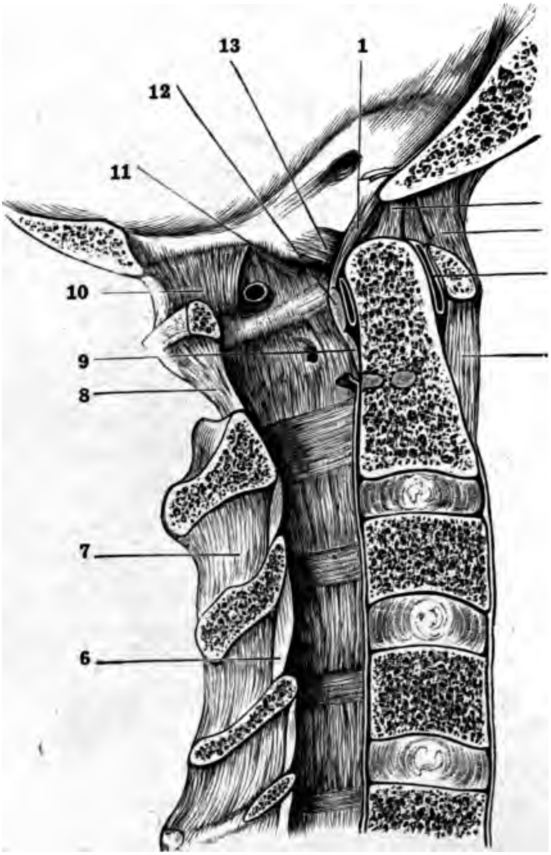


FIG. 49. — Sagittal section at the junction of the head and neck, showing the arrangement of the ligaments. 1, ascending portion of crucial ligament; 2, apical dental lig.; 3, anterior atlanto-occipital lig.; 4, atlanto-dental synovial sac; 5, anterior atlanto-epistrophic lig.; 6, ligamentum flavum; 7, interspinous lig.; 8, post atlanto epistrophic lig.; 9, descending portion of crucial lig.; 10, posterior atlanto-occipital lig.; 11, inner part of capsular lig. of atlanto-occipital joint; 12, transverse lig.; 13, left alar lig. (Morris.)

with the skull by its superior articular processes in such a manner as to permit the nodding movement of the head. The rotary movement of the head is rendered possible by the articulation of the atlas with the second cervical vertebra, the epistropheus (or axis), which presents beside two lateral sliding articulations a vertical process, the tooth (dens), about which the atlas rotates.

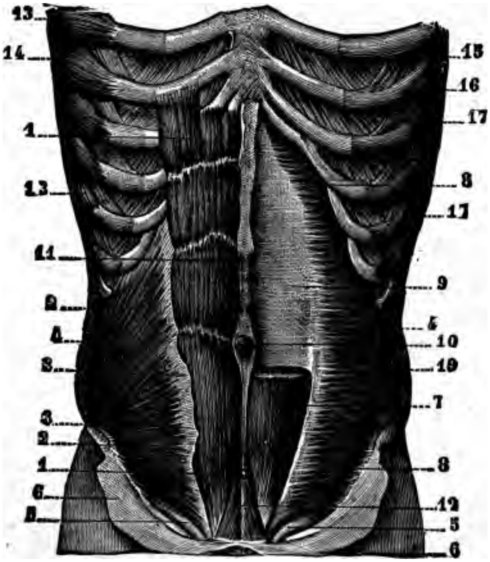


FIG. 50. — Deeper muscles of the abdominal wall. 1, rectus abdominis; 2, 3, internal oblique and cut end of its aponeurosis; 4, cut edge of external oblique; 5, spermatic cord; 6, aponeurosis of the external oblique turned down; 7, rectus abdominis, upper part removed; 8, 9, transversus muscle; 10, umbilicus; 11, 12, linea alba; 13, serratus anterior; 14, 15, cut edge of latissimus dorsi; 17, external intercostals; 19, cut edge external oblique. (Gould.)

The amount of motion between any two of the remaining vertebræ is not large, but the sum total is considerable so that the vertebral column may be said to possess considerable flexibility.

The Ribs. — The ribs (Fig. 51) may be divided into three groups of 7, 3, and 2 pairs respectively. All these articulate at one end with the spinal column, and in respect to the other end the ribs of the first group articulate with the sternum, of the second with the cartilage of the ribs above them, and the third end free with no articulation, and these are known as floating ribs. The direction of the ribs is such that if the sternal end be elevated, the antero-posterior diameter of the cavity of the thorax is increased, if the middle part of the rib be elevated, the transverse diameter of the thoracic cavity is increased. Between the ribs extend the intercostal muscles. The internal intercostals arise from the lower border of each rib and run obliquely forward and downward to be inserted into the upper border of the rib below. They fill the spaces between the ribs and their position is such that by contracting they elevate the sternum and also elevate convexities of the ribs so that the thoracic cavity is enlarged both antero-posteriorly and transversely. Conspicuous among the muscles attached to the ribs is the diaphragm. This muscle arises from the lower part of the sternum and the inner surfaces of the 6th and 7th lower ribs and from the bodies of the 2d to 4th lumbar vertebræ by two fleshy pillars

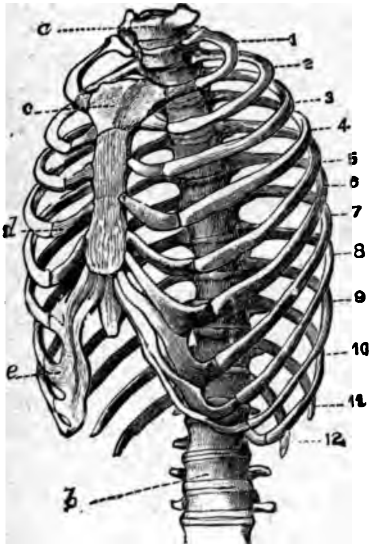


FIG. 51. — The ribs. *a*, *b*, vertebral column; 1–12, ribs; *c*, sternum; *d*, costal cartilages. (Huxley.)

(Fig. 52). From this somewhat circular origin the fibers of the muscle converge to the central tendon. In shape this muscle is not unlike an inverted tumbler. A small area at the center of the bottom of the tumbler represents the central tendon, the edges of the tumbler represent the origin of the muscle from the ribs, etc. Contraction of the fibers of the diaphragm rounds off, as it were, the bottom of the tumbler and thus decreases the volume of the abdominal cavity while it enlarges the cavity of the thorax (see Fig. 53).

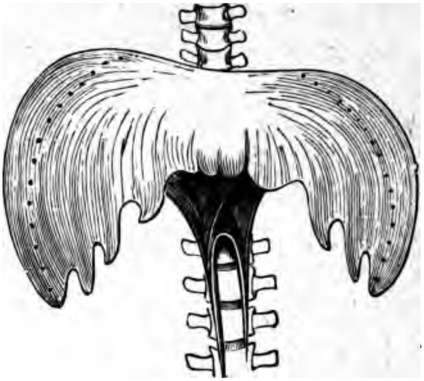


FIG. 52. — The diaphragm. Dotted lines indicate the descent in contraction. (Holden.)

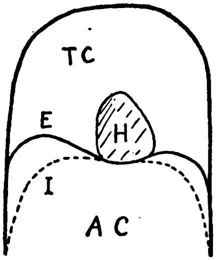


FIG. 53. — Diagram showing the change in position of the diaphragm on inspiration. *TC*, thoracic cavity; *AC*, abdominal cavity; *H*, heart; *E*, position of diaphragm when at rest, that is during expiration; *I*, position of diaphragm during inspiration.

The ribs and their cartilages give attachment to the following muscles: 1–7 to the pectoralis major muscle; 5–7 to the rectus abdominis; the lowest eight to the external oblique, the lowest six to the transversalis; and the lowest four to the internal oblique.

The Clavicle. — The clavicle (collar bone) articulates with the upper end of the sternum and with the acromial process of the scapula. Its anterior and superior surfaces in their lateral one third afford attachment to the deltoid muscle; its mesial one third to the sterno-cleido-mastoid muscle.

The sterno-cleido-mastoid (Fig. 48) arises by two heads from the upper end of the sternum and the mesial one third of the clavicle, and is inserted into the mastoid process of the temporal bone and into the lateral part of the rough curved line which runs laterally from the external occipital protuberance of the occipital bone. Its action is to depress and rotate the head.

The Scapula. — The scapula (shoulder-blade) has beside its articular surfaces for the clavicle and the humerus a broad flat blade which lies upon the thorax in the region of the second to the seventh rib inclusive. It is held in place by numerous muscles attached to it and to the thorax and gives origin to several important muscles moving the arm. The outer surface presents a bony ridge (spine) which terminates in the acromial process. Both spine and process afford attachment to the trapezius muscle and to the deltoid.

Above the articular surface for the head of the humerus (glenoid cavity) is the origin of the long head of the biceps muscle, while just below the glenoid cavity is the origin of the middle or long head of the triceps muscle.

The coracoid process (crow's beak) is a hook-like structure the tip of which gives origin to the short head of the biceps. The posterior or vertebral border gives attachment to the serratus anterior muscle.

The trapezius muscle (Fig. 54) arises from the inner (mesial) one third of the curved ridge running laterally from the external occipital protuberance of the occipital bone, the ligamentum nuchæ, the spinous processes of the last cervical and of all the thoracic vertebræ, and is inserted into the outer one third of the posterior border of the clavicle, the superior margin of the acromial process and the whole length of the superior border of the spine of the scapula. The muscle has two actions, the first upon the head which it draws backward and downward and the second upon the shoulder which it draws backward. The latter motion is modified in an upward and

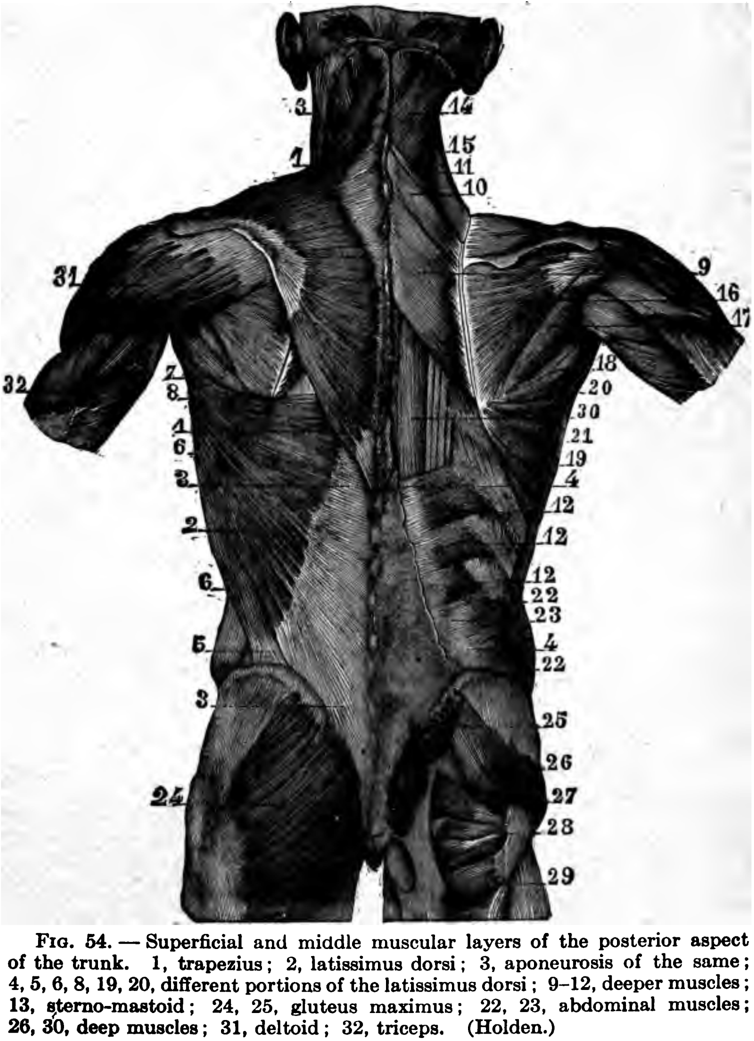


Fig. 54. — Superficial and middle muscular layers of the posterior aspect of the trunk. 1, trapezius; 2, latissimus dorsi; 3, aponeurosis of the same; 4, 5, 6, 8, 19, 20, different portions of the latissimus dorsi; 9–12, deeper muscles; 13, sterno-mastoid; 24, 25, gluteus maximus; 22, 23, abdominal muscles; 26, 30, deep muscles; 31, deltoid; 32, triceps. (Holden.)

downward direction, depending upon the particular fibers of the muscle involved in the contraction.

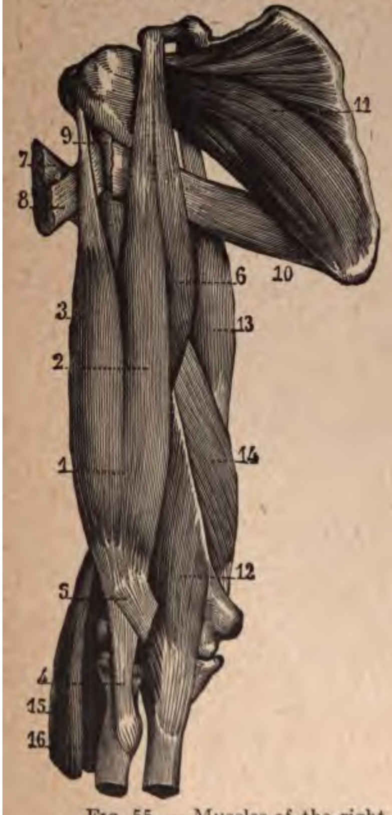


FIG. 55. — Muscles of the right shoulder and arm from in front. 1, 2, 3, 5, biceps and insertion of biceps into the fascia of the forearm; 4, insertion of the biceps into the tuberosity of the radius; 7, 8, insertion of the pectoralis major; 9, insertion of the latissimus dorsi; 6, 10, 11, shoulder muscles, scapula to humerus; 13, 14, two heads of triceps. (Holden.)

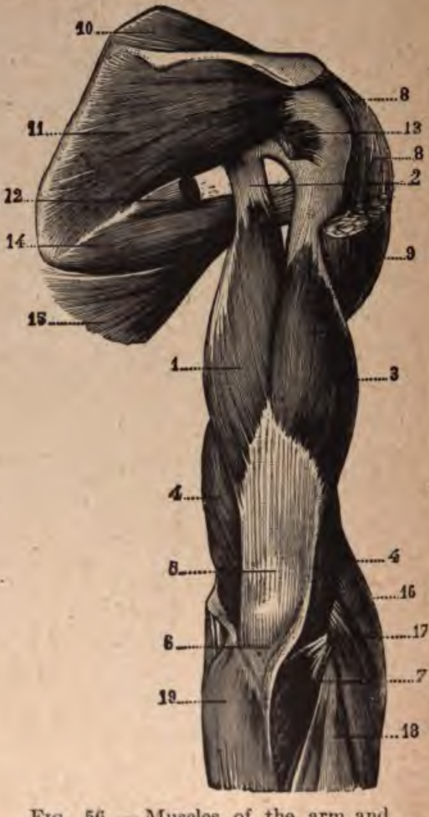


FIG. 56. — Muscles of the arm and shoulder, posterior view. 1, 2, 3, 4, 5, triceps; 6, attachment of triceps to olecranon; 8, 9, deltoid (portion removed); 10, 11, 12, 13, 14, muscles of shoulder from scapula to humerus; 15, latissimus dorsi; 16, 17, 18, 19, muscles of the forearm. (Gould.)

The serratus anterior muscle (Fig. 48) arises from the eight upper ribs by fleshy digitations. The fibers converge and are inserted along the whole length of the posterior border of the scapula. In quadrupeds this is the muscle upon which the body is slung, as it were, between the fore legs.

The Humerus. — On the anterior aspect of this bone near its upper extremity is a longitudinal groove (intertubercular groove) in which runs the tendon of the long head of the biceps muscle. Into the margin of the intertubercular groove is inserted the pectoralis major and the latissimus dorsi. The rough elevation (deltoid eminence) on the lateral aspect about one third of the distance from the upper end gives attachment to the deltoid muscle. The posterior aspect of the bone gives an extensive origin to the triceps muscle which covers most of the bone in this region. At the lower end of the humerus, mesially situated, is a groove easily felt during life which transmits the ulnar nerve, which on mechanical stimulation gives rise to the familiar sensation which has won for this region the name of "funny" or "crazy" bone.

The pectoralis major muscle (Fig. 48) arises from the cartilage of the first to seventh ribs, the sternum, and the sternal one half of the clavicle. The fibers of the muscle converge, and after crossing the intertubercular groove are inserted into the roughened external border of the groove. Its action is to draw the arm forward and downward.

The latissimus dorsi (Fig. 54) arises from the spines of the six lower dorsal and the lumbar and sacral vertebræ, the crest of the ilium and the three or four lower ribs and is inserted into the humerus at the intertubercular groove. Its action is to draw the arm downward and backward.

The deltoid (Fig. 54) arises from the outer one third of the anterior and superior surfaces of the clavicle, the outer margin and upper surfaces of the acromion, and the whole lower border of the spine of the scapula and is inserted into the deltoid eminence of the humerus.

The Ulna and Radius.—The ulna shows at the upper end two processes, a posterior or olecranon, and an anterior or coronoid, between which lies the surface for articulation with the humerus. Into the posterior region of the olecranon is inserted the triceps muscle. In the inner and anterior aspect of the radius near its upper end is a rough oval elevation (radial tuberosity) for the insertion of the biceps muscle. The triceps (the extensor of the forearm, Fig. 56) arises from three heads, an outer attached to the posterior surface of the humerus, an inner attached more mesially, and a middle or long head which is attached to the lower border of the glenoid cavity and is inserted into the olecranon process of the ulna. The biceps muscle (a flexor of the forearm, Fig. 55) arises by the long head from the upper margin of the glenoid cavity of the scapula, by a short head from the apex of the coracoid process and is inserted into the tuberosity of the radius.

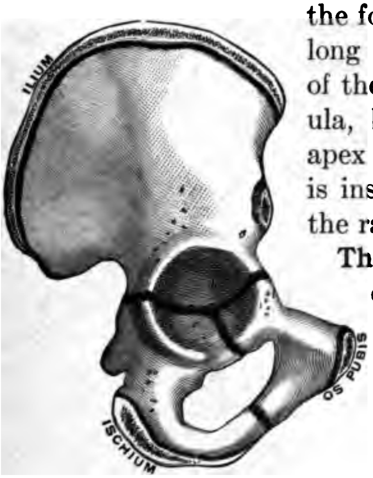


FIG. 57.— Development of os coxæ, showing the lines of separation between the ilium, ischium, and pubis. (Testut.)

The Hand.—The carpal bones, eight in number, are strongly bound together with ligaments. As in the case of the foot, there is but little motion between them and such as exists is due to the elasticity of the tissues. The metacarpals are five in number; the phalanges, fourteen.

The Pelvis.—The pubis, ischium, and ilium are distinct in young subjects, but about puberty they unite

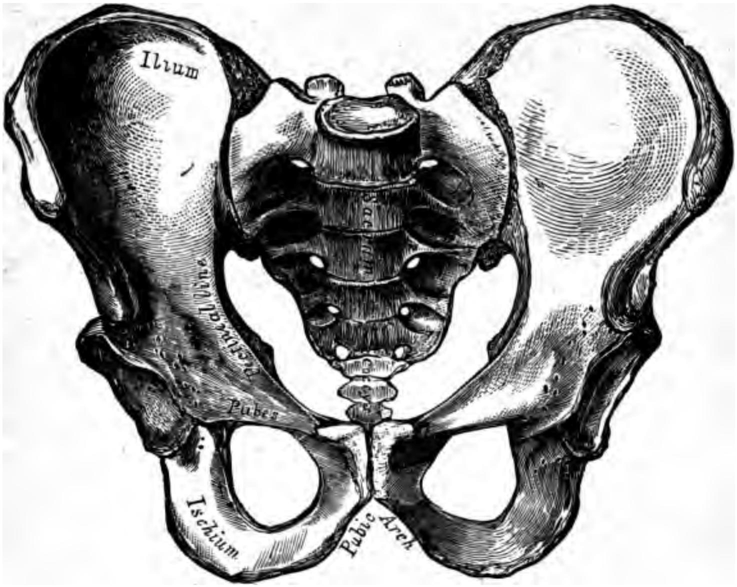


Fig. 58. — Human pelvis, male. (Kimber.)

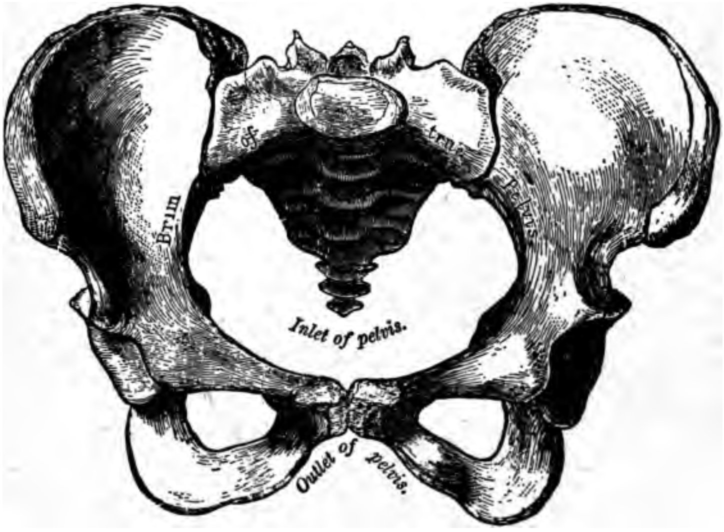


Fig. 59. — Human pelvis, female. (Kimber.)

to form a single bone, the os coxæ (or innominate) (Fig. 57). Above and behind, the two ossa coxarum articulate with the sacrum by what is normally a rigid joint; below and in front, the two pubic bones unite to form a symphysis (growing together) known as the symphysis pubis. The sacrum, coccyx, and the two ossa coxarum constitute the pelvis (basin). The basin is divided into two parts, an upper or false pelvis, and a lower or true pelvis, the division between them being the pectineal line (Figs. 58, 59). The upper border of the true pelvis is known by the obstetrical term, inlet. The pelvis has also an outlet below, which is bounded by the pubic arch in front, the coccyx behind, and laterally by the tuberosities of the ischium. The dimensions of the inlet and outlet are of great importance to those who bear children. They are on the average as follows:

Inlet. Antero-posterior diameter, 11 cm.
Inlet. Transverse diameter, 13.5 cm.
Inlet. Oblique diameter, 12.75 cm.

Outlet. Antero-posterior diameter, 11.5 cm.
Outlet. Transverse diameter, 11 cm.

A conception of the pelvis without due regard to its ligaments would be a very incomplete one. The ligaments are given in Fig. 61 *A* and *B*, which will serve to show the way in which the pelvic articulations are reinforced. The great ischiadic foramen transmits the great sciatic nerve.

To the pelvic bones are attached several groups of muscles. Those which form the abdominal wall are the external oblique, the internal oblique, the transversalis, and the rectus abdominis muscles. The external or descending oblique (Fig. 48) is attached to the eight lower ribs by fingerlike processes. The fibers run forward

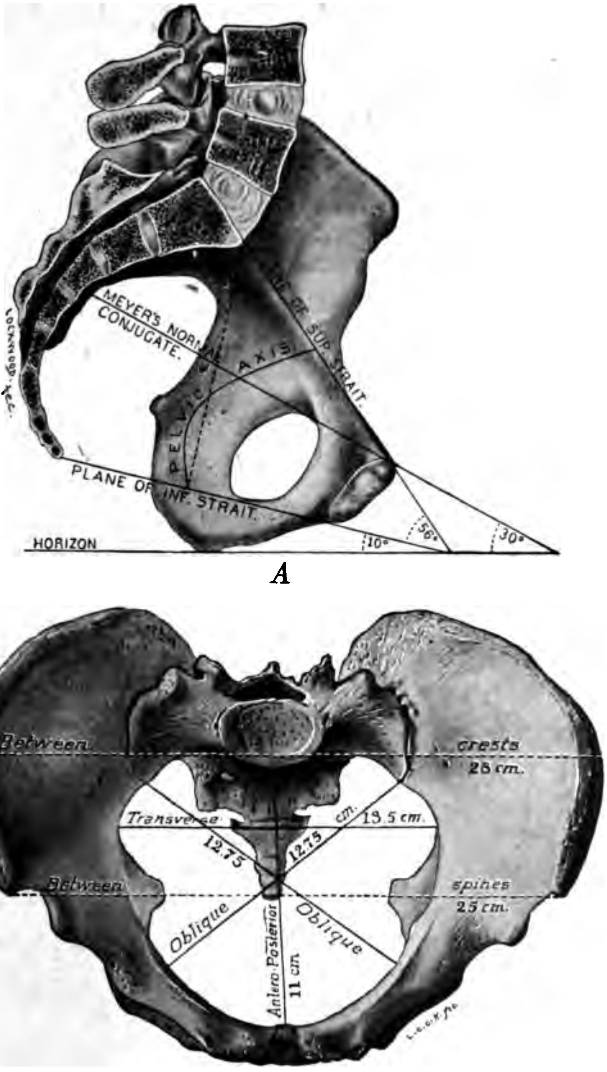


Fig. 60 — *A*, **sagittal** section through normal female pelvis. *B*, normal **female pelvis showing** diameters of superior strait or inlet. (Williams.) (**Copyrighted** by D. Appleton and Company.)

and downward and terminate in the anterior one half of the crest of the ilium and in the pubis near the symphysis. The lower edge of the muscle as it passes from the anterior superior spine of the ilium (Fig. 61 *A*) to the pubis is strengthened by tendinous tissue, and is known as the inguinal ligament. Towards the midline of the body the muscle ends in a broad, tendinous expansion (aponeurosis) which helps to form the anterior wall of the abdomen and is continuous with the similar structure of the opposite side. The internal oblique and transversalis end in similar aponeuroses in this direction which become fused in the midline of the body. The white fibrous tissue of which this medial structure is composed gives it the name of white line (linea alba). The linea alba extends from the symphysis pubis to the sternum.

The internal or ascending oblique (Fig. 50) is attached to the anterior two thirds of the crest of the ilium and the outer half of the inguinal ligament. Its fibers run upward and forward and terminate in the cartilages of the four lower ribs, and, by its aponeurosis, in the linea alba.

The transversalis (Fig. 50) is attached to the outer one third of the inguinal ligament, the anterior two thirds of the crest of the ilium, and the inner surface of the cartilage of the six lower ribs. Its fibers run transversely and terminate in the pubis near the symphysis and in the linea alba.

The rectus abdominis (Fig. 50) gives muscular support to the region for which the other muscles have provided only their strong but rigid aponeuroses. The fibers of this muscle run vertically. They lie laterally from the linea alba and medially from the fleshy parts of the other three muscles. They are inclosed between the aponeuroses of the other three muscles and extend from the pubis near the symphysis to the 5th, 6th, and 7th

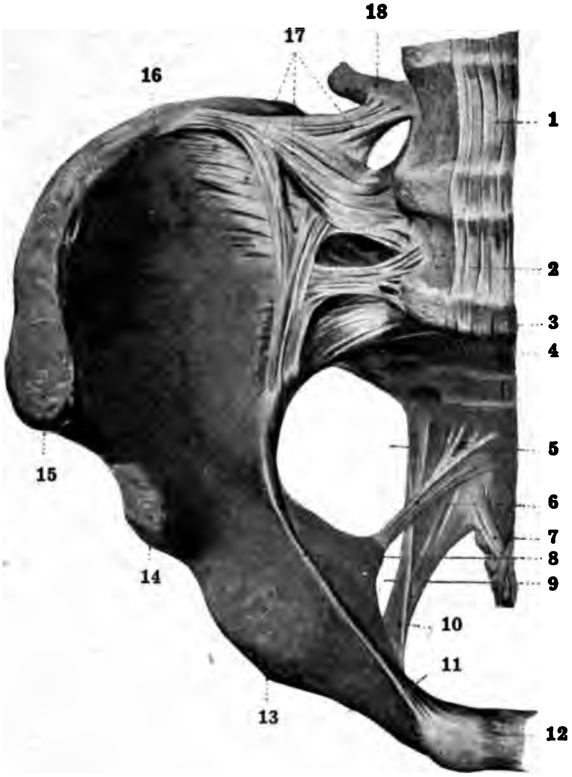


FIG. 61 *A*. — Ligaments of the pelvis from before. 1, anterior longitudinal ligament; 2, body of fifth lumbar vertebra; 3, promontory of the sacrum; 4, anterior sacroiliac ligament; 5, great ischiadic foramen; 6, sacrospinous ligament; 7, anterior sacrococcygeal ligament; 8, terminal line or brim of true pelvis; 9, small ischiadic foramen; 10, sacrotuberous ligament; 11, superior pubic ligament; 12, symphysis pubis; 13, ilio-pectineal elevation; 14, anterior inferior iliac spine; 15, anterior superior iliac spine; 16, iliac fossa; 17, iliolumbar ligament; 18th transverse process of the fourth lumbar vertebra. (Spalteholtz.)

ribs. The action of these four abdominal muscles is readily surmised from their position; they oppose the muscles of the back in flexing the thorax on the pelvis. or vice versa and they compress the abdominal viscera, an action which aids in the expulsion of objects from the hollow viscera of the abdomen, namely, the rectum, uterus, and urinary bladder, and hence are of the utmost importance in defecation, in parturition, and to a lesser degree in micturition (p. 237).

To the pelvic bones are also attached several muscles which move the lower extremity. They are the iliacus (flexor of the thigh) arising from that portion of the ilium which forms the floor of the false pelvis (iliac fossa), the extensors and abductors of the thigh arising from the outer aspect of the ilium, the adductors of the thigh arising from the ischium and pubis between the tuberosity of the former and the symphysis pubis, and the flexors of the leg which arise from the tuberosity of the ischium.

The Femur. — The femur is a large bone, the head of which articulates with the cavity of the os coxæ known as the acetabulum. Near the head are two tuberosities, a larger above and a smaller below known as the great trochanter and the lesser trochanter respectively. These trochanters are joined both anteriorly and posteriorly by two rough lines to which the capsule or covering of the joint is attached. Two roughened ridges (linea aspera) run along the posterior aspect of the femur, arising one from each of the trochanters. They afford attachment to the adductors and abductors of the thigh and to the extensors of the leg. Into the great trochanter is inserted the gluteus medius muscle (an abductor of the thigh) and into the lesser trochanter is inserted the common tendon of the psoas and iliacus muscles. A description of these muscles is as follows:

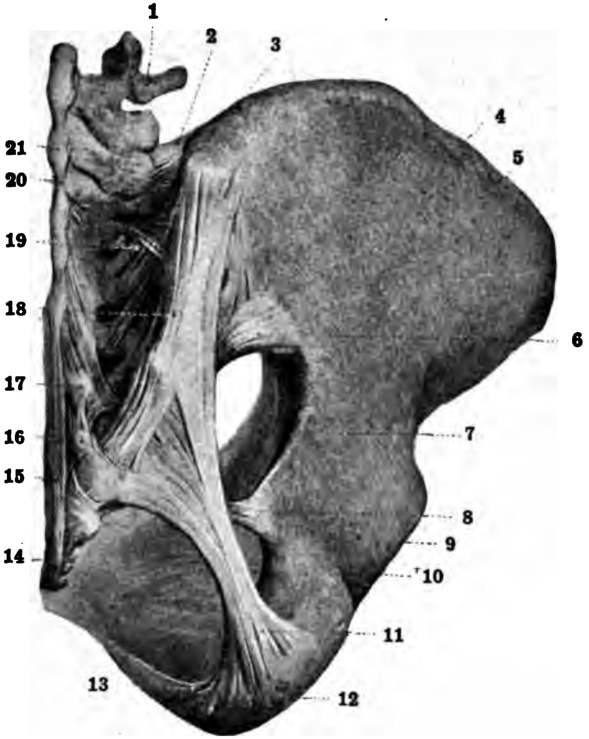


FIG. 61 *B*. — Ligaments of the pelvis from behind. 1, transverse process of the fourth lumbar vertebra; 2, ilio-lumbar ligament; 3, posterior superior iliac spine; 4, wing of the ilium; 5, iliac crest; 6, posterior inferior iliac spine; 7, great ischiadic foramen; 8, sacro-spinous ligament; 9, acetabulum; 10, small ischiadic foramen; 11, sacro-tuberous ligament; 12, tuber of the ischium; 13, falciform process; 14, coccyx; 15, superficial posterior sacro-coccygeal ligament; 16, horn of the coccyx; 17, horn of sacrum; 18, long posterior sacro-iliac ligament; 19, short posterior sacro-iliac ligament; 20, interspinal ligament; 21, spinous process of fifth lumbar ligament. (Spalteholtz.)

The iliac fossa which forms the floor of the false pelvis gives a broad insertion to the iliac muscle which fills the shallow depression of this part of the bone (Fig. 63). The fibers of this muscle converge and are inserted by means of the common tendon of the psoas and iliacus into the lesser trochanter of the femur. The psoas magnus muscle (Fig. 63) arises from the bodies and processes of the last thoracic and all the lumbar vertebræ. Its fibers pass downward through the false pelvis and are inserted into the lesser trochanter of the femur by the tendon which it has in common with the iliacus. The action of these two muscles is to flex the femur upon the pelvis or the trunk and pelvis upon the thigh. The adductors of the thigh (Fig. 64) arise from the tuberosity of the ischium and from the anterior parts of the ischium and pubis, and they are inserted into the whole length of the linea aspera of the femur.

The abduction of the femur is performed by the gluteal muscles which form the buttocks. They arise from the whole external surface of the ilium above the hip joint (Fig. 51), and are inserted into the great trochanter of the femur and to the upper part of the linea aspera. One of these muscles, the gluteus maximus, also serves as an extensor for the thigh. This extensor is aided by the flexors of the leg, which when they act at the same time as the extensors of the leg, extend both leg and thigh upon the trunk. The lower end of the femur consists of two articular eminences or condyles for articulation with the head of the tibia. Immediately above each of these, on the posterior aspect, is a roughened area for the attachment of the two heads of the gastrocnemius muscle.

The Patella. — The patella lies in front of the knee joint enveloped by the tendon of the quadriceps extensor

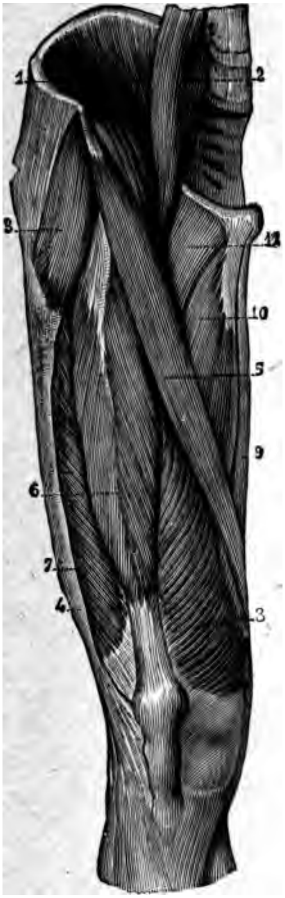


FIG. 62. — Flexors of the thigh and extensors of the leg. 1, iliacus; 2, psoas; 6, 7, 8, parts of the quadriceps femoris, below which is the patella; 10, an adductor. (Gould.)

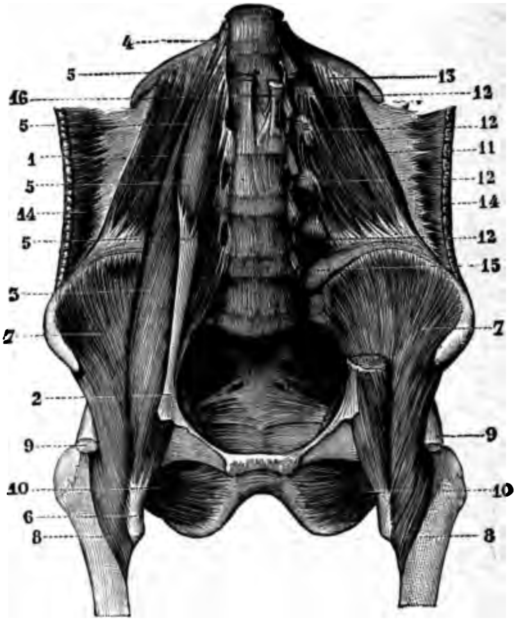


FIG. 63. — Flexors of the thigh. 3, psoas; 7, iliacus; 8, their insertion into the lesser trochanter. (Gould.)

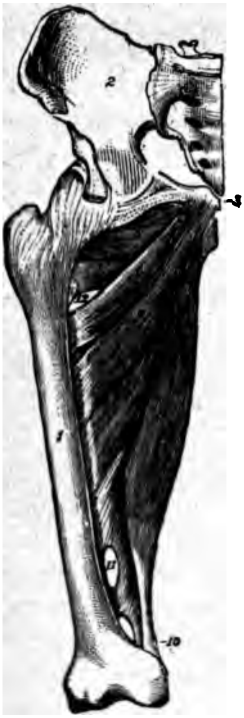


Fig. 64. — Adductors of the thigh. 1, femur; 2, ilium; 3, symphysis pubis; 5, 6, 7, 8, 9, 10, adductors; 11, 12, openings for vessels passing to back part of thigh. (Gould.)

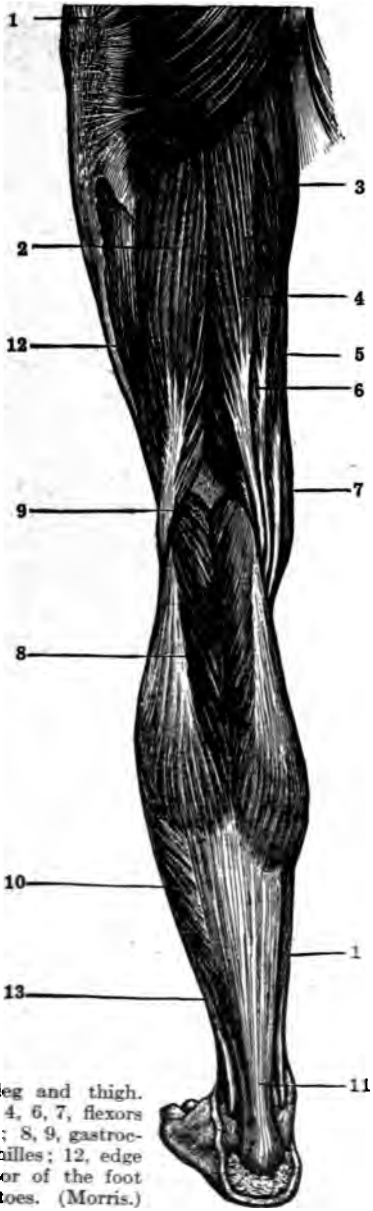


Fig. 65. — Posterior view of the leg and thigh. 1, insertion of gluteus maximus; 2, 3, 4, 6, 7, flexors of the leg; 5, an adductor of the thigh; 8, 9, gastrocnemius; 10, soleus; 11, tendon of Achilles; 12, edge of quadriceps femoris; 13, an extensor of the foot (peroneus longus); 14, long flexor of the toes. (Morris.)

muscle which arises from the femur above and is inserted into the leg below.

The Tibia and Fibula. — Near the upper extremity of the tibia, on its anterior aspect, is a rough elevation (tubercle) for the attachment of the tendon of the quadriceps extensor muscle (Fig. 62). The extension of the leg is due chiefly to the action of this muscle. Its most important attachments are on the femur, from the whole length of the lateral part of the linea aspera clear around the front of the femur to the whole length of the mesial part of the linea aspera. From this extensive insertion arises a very extensive muscular mass which converges to the broad tendon which envelops the patella and is inserted into the capsule of the kneejoint and especially into the tuberosity of the tibia. That part which extends from the patella to the tuberosity of the tibia is known as the patellar ligament. The posterior and mesial aspect of the head of the tibia and the lateral and anterior aspect of the head of the fibula afford attachment to the flexors of the leg. These muscles (Fig. 65) arise chiefly from the tuberosity of the ischium; their tendons are felt behind the knee joint on both sides near their insertion into the head of the tibia and of the fibula. The lower end of the tibia forms a bony lump readily felt at the mesial aspect of the ankle and known as the median malleolus. A corresponding prominence on the outer surface of the ankle, the lateral malleolus, is formed by the fibula. The anterior aspect of the bones of the leg is occupied by the origin of the flexors of the foot, while the posterior affords attachment to the extensors. Among the latter is the soleus muscle (Fig. 65), which arises from the upper one half of the fibula.

The Foot. — The ankle joint is formed by the articulation of the tibia and fibula with the os talus of the tarsus. Into the calcaneus (heel bone) is inserted the tendon of Achilles (the common tendon of the gastrocnemius and soleus muscles). The gastrocnemius muscle (Fig. 65) arises by two heads from the condyles of the femur and after uniting with the tendon of the soleus to form the tendon of Achilles (tendo calcaneus, the conspicuous tendon behind the ankle joint) is inserted into the calcaneus. The soleus arises from the upper half of the tibia and fibula. With the gastrocnemius it forms the calf of the leg. Viewed from the mesial side the sole of the foot is seen to be arched from before backward (longitudinal arch). A second arch (transverse arch) occurs at right angles to the longitudinal arch in the region of the metatarsal bones (Fig. 66). The loss of integrity of one or both of these arches causes great pain and disability.

Fig. 66 *B.* — Transverse section of the foot across the heads of the metatarsal bones, showing the anterior, metatarsal or transverse arch of the foot.

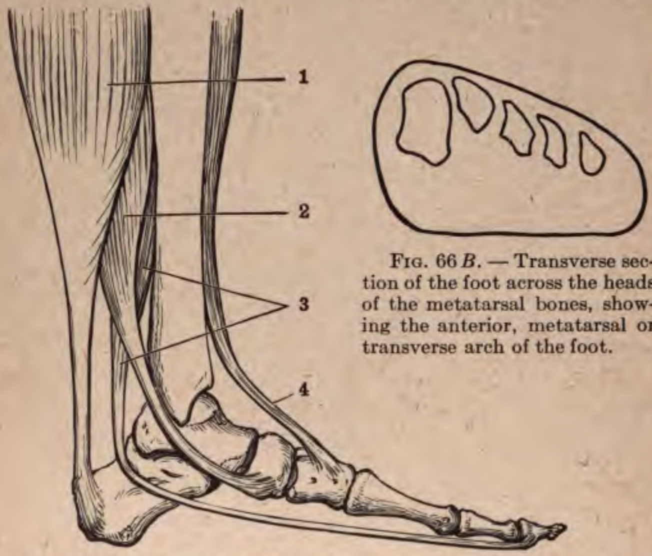


Fig. 66 *A.* — Longitudinal arch of the foot. The muscles controlling the movements of the foot are also shown, namely 1, the calf muscles; 2, tibialis posterior; 3, long flexor of the great toe; 4, tibialis anterior. (Morris.)

CHAPTER V

THE NERVOUS SYSTEM

We have seen (p. 9) that in unicellular organisms like the amœba the response of a stimulus is not confined to the region stimulated but that in the response the whole organism takes part. This property, through which the effects of a stimulus are spread to distant parts of an organism, thereby provoking a general and unified response, is known as conduction.

As in the amœba so in complex organisms such as ourselves the response to a stimulus is not confined to the region stimulated. We too possess the property of conduction but it is not equally present in all our cells. Conduction is especially characteristic of a certain class of cells, the nerve cells or neurones. These cells are the units which, taken together, constitute the nervous system. The neurones are not only conducting but also irritable, the latter often to an extraordinary degree, and their endings may be so specialized as to respond to only one sort of stimulation, *e.g.* that of odors. But often the neurones receive their stimuli through the intermediation of neuro-epithelial cells about which their processes end and which are often very highly developed and specialized, as in the case of the eye and the ear.

The Neurone. — The typical neurone (Fig. 67) consists of a cell-body and its processes. The former possesses a nucleus surrounded with cytoplasm containing granules known as tigroid bodies. The processes or prolongations of the cytoplasm are of various lengths and forms. Some are short and branch profusely and are therefore known as dendrites; some are long, they may be as much as a meter long, with but few branches except just at the end of the process (terminal aborization), and are called axones.

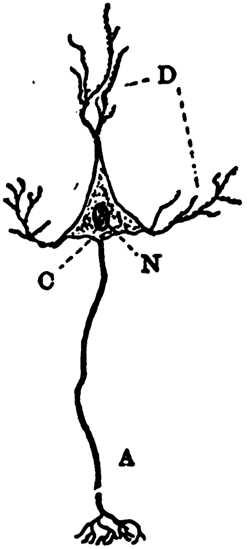


FIG. 67. — Diagram of a neurone. *A*, axone arising from the cell-body and branching at its termination; *D*, dendrites; *C*, cytoplasm, and *N*, nucleus, which compose the cell-body.

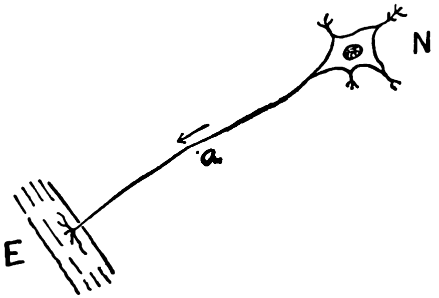


FIG. 68. — An automatic nervous mechanism. This consists of a motor end-organ (*E*), which may be a muscle or a gland, and a motor or efferent neurone (*N*). The latter is stimulated by changes in its environment and reacts by generating a nerve impulse which passes along its axone (*a*) to the end organ, which it throws into activity (or the reverse, see p. 40).

Automatic Action. — The simplest conception of nervous action is that involving a single neurone connected with a muscle fiber (Fig. 68). The former is stimulated by changes in its environment, the effect of the stimulus spreads to the muscle along the axone and causes the muscle fiber to enter into functional activity, that is, to contract. In the higher animals the environment of the neurone is represented by the blood-stream. For example, the blood acting upon the cells of the respiratory center stimulates them so that nerve impulses are sent out along their axones to the muscles of respiration, which in turn respond to the impulse by contracting. It is probable also that the very primitive act of locomotion is brought about in a similar way. Such a mode of action on the part of the neurones is known as automatic and the neurones are said to possess automaticity.

Reflex Action. — In addition to the effect of changes in the blood stream, neurones respond to the changes in distant parts affecting them through the power of conduction of other neurones. This second form of activity is known as the reflex. The simplest reflex action involves two neurones placed end to end; the free end of one neurone being connected with some sense organ (*e.g.* the ear) or some sensory surface (*e.g.* the skin) while the free end of the other neurone is connected with some motor organ (*e.g.* gland, muscle). (See Fig. 69.)

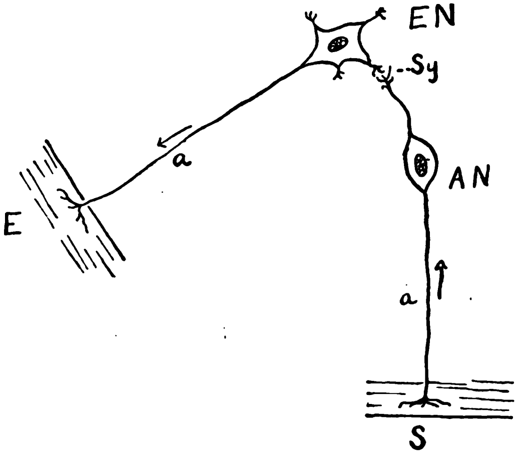


Fig. 69. — Diagram of a reflex mechanism or "reflex arc." Here there are two neurones, an efferent or motor neurone (*EN*), and an afferent or sensory neurone (*AN*); the axone of the former terminates as before in a motor end-organ (*E*); the axone of the latter in a sensory surface (*S*). An impulse starting from *S* traverses *AN*, passes over the region where the dendrites of the two neurones lie in contiguity (synapse, *Sy*) and then through the second neurone (*EN*) to the motor end-organ (*E*).

To make these relations clear let us suppose that at *S* (Fig. 69) the "sensory" neurone terminates in the mucous membrane of the nose and that the "motor" neurone makes connection with the muscles of respiration at *E*. Let us further suppose that some fine particles of pepper are wafted into the nose and lodge upon the surface of the nasal mucous membrane. The outcome is a chemical stimulation of the sensory nerve endings at *S*. Since the nerve cells are highly conducting, this stimulus has not merely a local effect. It sets up a change in the neurone which travels from *S* through *AN* to *Sy*. It then crosses at *Sy* to *EN* and passes thence to *E* and at *E* acts as a stimulus to the respiratory muscles, which in response to the stimulus contract, producing that peculiar expiratory phenomenon known as a sneeze.

The stimulus need not be applied directly to the sensory nerve ending at *S*. The neurone may end in a group of epithelial cells (neuro-epithelium) especially adapted to receive some particular form of stimulus. For example, suppose *S* forms connections with the retina of the eye and *E* be the secreting cells of the tear gland. Now if bright light falls upon the retina, it affects the epithelial cells composing it and this sets up a change which travels from *S* through *AN* over *Sy* to *EN* and thence to *E* the secretory cells, with the result that there is a copious secretion of tears, *i.e.* the eye "waters."

Tonus. — It has already been stated (p. 38) that muscles may exhibit tonus, a state of subdued but continuous activity. Motor neurones may also exhibit this phenomenon. For example, the nerve fibers which run to the muscular coats of the blood vessels are continually carrying impulses to those muscles, and the neurones being thus in tonic activity the muscles are also kept in tonic activity, *i.e.* they are kept in the state of slight contraction which can be abolished by cutting the nerve fibers which go to them, or by destroying the tonus of the motor neurone. Other familiar examples of tonus are the tonic contraction of the sphincters of the urinary bladder, of the anus, and of the pupil. This tonus, in so far as it is of nervous origin, disappears on section of the nerves going to these muscles.

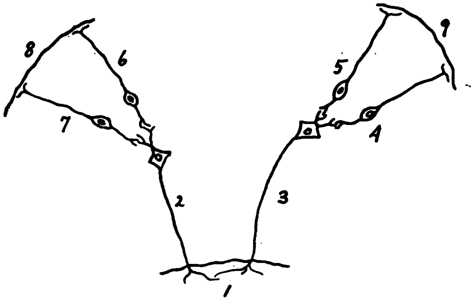


FIG. 70. — Diagram of mechanism involved in tonus, excitation and inhibition, direct and reflex. 1, an organ which is normally in tonic activity; 2, efferent neurone also in tonic action, inhibiting the tonic activity of the organ (1); 3, efferent neurone also in tonic activity, exciting the organ (1). Now since 2, 3 are in tonic activity, they too may be inhibited by afferent inhibitory fibers. 4, afferent neurone capable of exciting 3; 5, afferent neurone capable of inhibiting 3; 6, afferent neurone capable of inhibiting 2; 7, afferent neurone capable of exciting 2. For example, suppose 1 is the heart which beats normally independently of all nervous connections. If 2 be destroyed the inhibitory effect of 2 upon the heart is removed so that the heart beats faster; if 2 be stimulated the heart will beat more slowly. Normally 2 is affected only through 6 and 7; the action of 6 when stimulated is to decrease the tonic action of 2 and thus quicken the heart, while the action of 7 when stimulated is to increase the action of 2 and thus slow the heart. Both 6 and 7 are stimulated at 8, where they end in some sense organ or sensory surface which receives its stimuli from some source outside of the organism. If this outside stimulus acts continuously then 6 or 7 or both may be in tonic activity also. After the preceding statement a discussion of the relations of 1, 3, 4, 5, and 9 would be superfluous.

Excitation and Inhibition. — Whenever a tissue cell is in tonic activity it is possible to influence it in two directions, namely, either to increase its tonus or to diminish it (p. 38). If, for example, the neurones which supply the voluntary muscles possess tonus, then it is possible either to increase the activity and consequently to call forth a contraction of the muscle or to diminish their activity and consequently to abolish the tonus of the muscle.

The neurones which increase activity are known as excitatory; while those which decrease activity are the inhibitory. Let us now modify Fig. 69 to conform to this last conception, that of excitatory and of inhibitory neurones. If we suppose that we have an organ that possesses tonus and that this organ is supplied with both excitatory and inhibitory efferent neurones and that each of these efferent neurones is itself in tonic activity and is in turn supplied with both excitatory and inhibitory afferent neurones, the resulting relations will be as shown in Fig. 70.

Describing a Neurone. — After what has been said it is clear that in describing a neurone we need only state the origin and destination of the impulses which pass over it, and also its action, whether excitatory or inhibitory. For example, we may describe 2 (see Fig. 70) as an inhibitory neurone carrying impulses, let us say to the heart from the cardio-inhibitory center, this being the region of the brain where the cell body and dendrites of 2 are situated. Or again, 7 may be described as an excitatory neurone carrying impulses, let us say from the stomach to the cardio-inhibitory center. It is sometimes convenient, though unnecessary, to add whether the neurone in question is afferent or efferent, *e.g.* 2 (Fig. 70) is an efferent inhibitory neurone from the cardio-inhibitory center to the heart and 7 is an afferent excitatory neurone from, let us say, the stomach to the cardio-inhibitory center.

Specific Nerve Energy. — The function of a neurone depends not upon any property of its own but upon its anatomic connections. If it be a sensory neurone it is stimulated normally in a certain peculiar way depending on the construction of its endings; if it be a motor neurone it affects only that motor end-organ with which it is connected.

Complexities of the Reflex Arc. — Figs. 71, 72 show a considerable increase in complication over Fig. 69, but the relations in the nervous system are still more complex. For every afferent neurone connects either directly or indirectly with many efferent neurones and efferent neurones are connected either directly or indirectly with many afferent neurones.

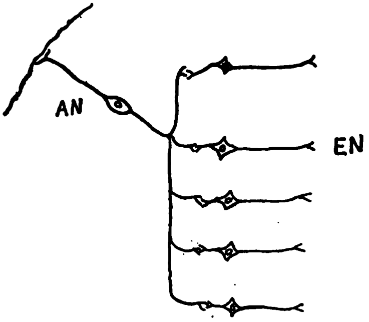


FIG. 71. — Diagram of a reflex arc involving several motor neurones; no localized reflex center. *AN*, afferent neurone; *EN*, efferent neurones.

Reciprocal Innervation.—Among the interesting and important of these complexities is the arrangement which permits the stimulation of a single sensory neurone to cause the excitation of one group of muscles, and the inhibition of the opposing group. It has been found, for example, that when a limb is flexed in reflex response to a stimulus locally applied, the excitation of the flexors is accompanied by a relaxation of the extensors (Fig. 73).

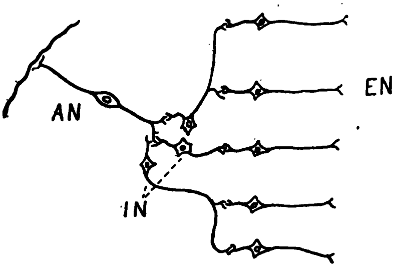


FIG. 72. — Diagram of reflex arc involving several motor neurones; interposed neurones form a localized reflex center. *AN*, afferent neurone; *EN*, efferent neurones; *IN*, interposed neurones.

Nerve Patterns.—A reflex which is so complicated and so beautifully coördinated as the flexion or extension of a limb, or as the sneezing reflex, implies that among the infinite paths and connections in the central nervous system there must be an interlacing of complex patterns which are more or less independent. If an impulse is started in one of these patterns it explodes, so to speak, every neurone in that pattern until the end organ (or organs) is reached and that too is then thrown into operation, all with the precision of a piece of machinery.

These patterns are partly inherited, such as the nervous complexes which control the viscera, and partly acquired. The acquisition of the skilled movements, such as walking and swimming and the manual arts, is merely the development of new nerve patterns. The patterns, though usually distinct, may become confused under the action of certain drugs and poisons which apparently so lower the resistance of all paths and so increase the irritability of the nervous system that the stimulus which ordinarily calls forth an appropriate and coördinated response now produces only a generalized convulsion involving all parts of the body. For example, if we decapitate a frog to eliminate all voluntary movements and then pinch one of the hind toes, the frog will with a very nice movement withdraw the foot in question. Here we see the stimulus of the few neurones resulting in the passage of the nerve impulse through a

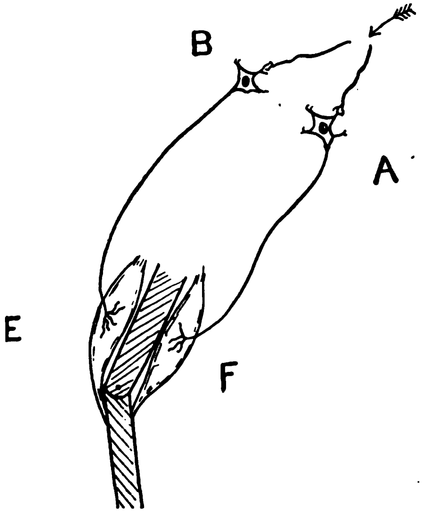


FIG. 73. — Diagram showing mechanism of reciprocal innervation. *E* and *F* are two muscles antagonistic in action, *E* being an extensor, *F* a flexor. *A* and *B* are the neurones which transmit impulses to *F* and *E* respectively and through whose tonic activity the tonus of *F* and *E* is kept up. If the joint is to be flexed, impulses pass in the direction of the arrow to *A* and *B*, with the result that *A* is excited and causes a contraction of *F*, while *B* is inhibited and causes a relaxation of *E*.

nerve pattern which involves the motor neurones of quite a number of muscles which act in perfect harmony and result in a protective movement. But if a little strychnia be injected into the animal in question, the slightest touch of the same toe will cause the animal to become rigid through the contraction of all the muscles of the body. Here the nerve impulse started by the stimulus is not confined to the usual nerve pattern; it involves many paths which include a vast number of motor neurones.

Centers. — The region where the impulse passes over from the afferent to the efferent neurone is called the reflex center. In the case of very simple responses, *e.g.* the knee-jerk (p. 96), the center is a circumscribed region near the place of entrance of the afferent fibers and of exit of the efferent fibers from the cord. It is obvious, however, that when a reflex is complicated and involves the motor neurones at different levels of the cord, the center must either be a diffuse thing (Fig. 71), or, if circumscribed, must consist of neurones interpolated between the afferent and the efferent neurones (Fig. 72). The centers which physiologists have been unable to localize may be of the former sort, *e.g.* cardio-accelerator center (see p. 154). Of the latter there are numerous instances, of which may be cited the respiratory center and the vaso-constrictor center, both of which are situated in the medulla. The former controls the respiratory movements; the latter, the caliber of the blood vessels. Since the respiratory movement is the result of many muscles acting harmoniously and with nice adjustment of each to the others, the respiratory and similar centers are known as coördinating centers. Without the respiratory center the separate respiratory muscles might be brought into play reflexly, but the rhythmic, delicately balanced contractions which result in sucking air into the lungs would be wanting.

It does not follow that the motor end organ must be necessarily operated by but one of these mechanisms. For example, the extensors of the leg may be operated as part of a very simple mechanism as in the case of the knee-jerk, or as part of a more complex mechanism as the extensor reflex which involves the thrusting out of the whole limb, or as part of a still more complicated mechanism as in locomotion. In each case a higher degree of coördination is required and a correspondingly more complex mechanism brought into play.

Nerve Impulse. — So far, the nerve impulse has been referred to without comment. The term signifies that change in the substance of the neurone which is originated by a stimulus and which progresses through the neurone. The path of the impulse may vary in length. It proceeds from neurone to neurone until the motor end-organ is reached, where it causes that organ to change its state of activity either in the direction of increase (excitation) or of decrease (inhibition). But little is known of the exact nature of this change except that it is probably chemical, that it requires for its occurrence the presence of oxygen, and that it progresses with a great velocity, 27 m. per second in the axone, though probably somewhat slower in the cell-body and at the region of contact between adjacent neurones (known as the synapse). The velocity of the nerve impulse may be altered by various circumstances or even interrupted altogether. Examples of the ways in which the nerve impulse can be " blocked " are familiar. Such are the effect of cooling by means of the ethyl-chlorid spray, the effect of pressure on the sciatic nerve as when one's foot "goes to sleep," the effect of drugs, such as cocain, novocain, and so forth.

Metabolism and Histologic Pictures. — The activity of the neurone is accompanied by a vigorous consumption of oxygen with a corresponding production of carbon dioxide, and by histologic changes in the cell-body. The latter have been shown for example in the sparrow, where as a result of a day of actively flying about the nuclei and cell-bodies of the neurones become shrunken and the tigroid bodies dissolve and disappear (Fig. 74).

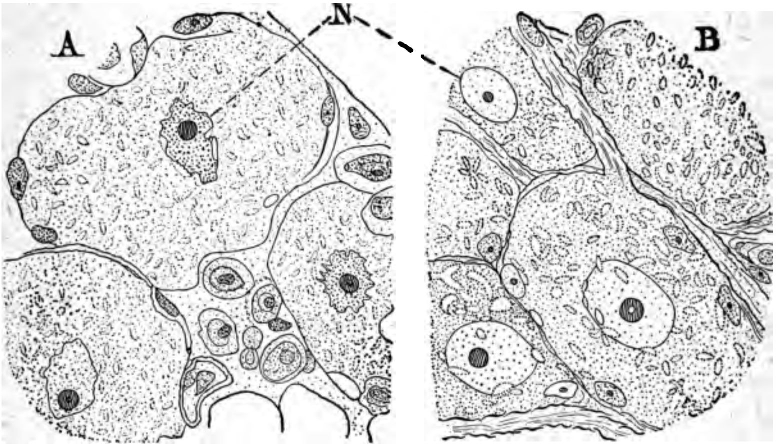


FIG. 74. — Nerve cells from English sparrow, to show the daily variation in the appearance of the cells due to normal activity. *A*, appearance of cells at the end of an active day; *B*, after a night's rest. Note the difference in nuclei and cytoplasmic granules. (Hodge.)

In fact, the condition of the nuclei and granules may be taken as an index of the working capacity of the neurone. It is probable that the substances produced by the activity of the neurones produce a depression of the irritability of the nervous system as in the case of muscular activity.

The Knee-jerk. — Since it has been clearly shown that the character of the reflexes is more or less modified by the condition of the nerve centers, it follows that a study of the reflexes in patients may be resorted to to gain information regarding the condition of the centers. Thus normal reflexes would be taken to indicate normal centers while abnormal reflexes would lead to the diagnosis of some diseased condition of the centers. Among the reflexes which are of the greatest importance in this connection is the knee-jerk. This reflex is elicited by a light blow upon the patellar tendon (see page 83), in response to which the leg is extended with a jerk. Not only is this reflex profoundly modified (exaggerated or abolished) by grave diseases of the nerve centers, but the minor variations in the intensity of the reflex serve as a sensitive indicator of the irritability of the nerve centers. During sleep the reflex is absent but in conditions of mental excitement it is increased. It is also more pronounced after meals and after resting than it is during fasting or fatigue.

Degeneration and Regeneration. — If the simple unicellular organisms be cut in two in such a manner that one part contains the nucleus and the other does not, the fate of the part which does not contain the nucleus is death, while the part which contains the nucleus lives on as usual and soon grows to be as large as it was before. This result is quite comparable to that which occurs in the section of the neurone or nerve cell. If, for example, a nerve (bundle of axones) be cut in two, the parts of the nerve fibers (axones) which are in connection with the cell-bodies continue to live while the parts which have been severed from the cell-bodies degenerate and disappear. Naturally when the path of conduction has been destroyed, the parts [illegible] nerve cease to function. If the nerve contains fibers for the muscles and glands of the part, there results a motor paralysis; if it contains fibers for the skin, the paralysis is sensory. To restore the paralyzed part to its normal condition it is simply necessary to provide an appropriate path for the growth of the nerve fibers still connected with their cell-bodies. If this is done, the fibers which are still in connection with the cell-bodies will grow out among the degenerating fibers, will finally replace them and form connection with the parts temporarily paralyzed, so that after an interval of some weeks function is restored completely.

Anatomic Relations and Arrangement of the Neurones. — Taking as our unit of structure the neurone, we shall now proceed to build up the nervous system, adding bit by bit until we have gone far enough to give a fair idea of its essentials.

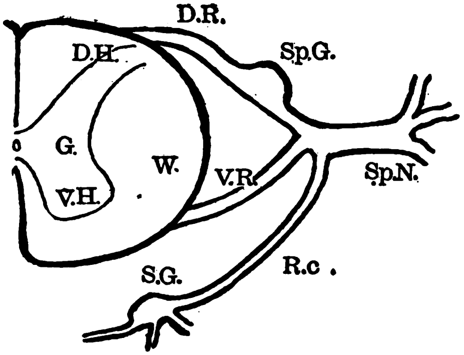


FIG. 75. — Diagram of cross section of spinal cord. *G*, gray matter; *V.H*, ventral horn of gray matter; *D.H*, dorsal horn of gray matter; *W*, white matter; *Sp.N*, spinal nerve; *V.R*, ventral root; *Sp.G*, spinal ganglion situated on the dorsal root; *S.G*, autonomic or splanchnic ganglion; *R.c*, ramus communicans (communicating branch) between the somatic or spinal system and the splanchnic or autonomic system.

Figure 75 shows a cross section of the spinal cord. It is for the most part a shiny white but in the center there is an H-shaped discoloration which is yellowish in colour. The former (white matter) is composed of axones running longitudinally, the latter (gray matter) is composed of cell-bodies and endings of the nerve processes. Fig. 76 shows the arrangement of the neurones in such a cross section.

D indicates the dorsal aspect of the cord, *V* the ventral aspect. 1, 2, 3 is a sensory neurone whose impulses pass from 1 (the direction of the end organ) to the cell-body 2, and thence from 2 to the cord, where the process enters the gray matter and forms a synapse with a motor neurone 4, 5, 6, so that an impulse passing from the sensory neurone is promptly returned through the motor neurone 4, 5, 6, through which it reaches the motor end organ. This is the mechanism of the simplest sort of reflex. Some sensory neurones, as 7, 8, 12, send their axones to end in the gray matter of the opposite side of the spinal cord. Still other sensory neurones (10, 11, 9) do not enter the gray matter at once but run in the white matter toward the head, sending branches from time to time into the gray matter of the same or opposite side to form synapses with motor neurones. The cell-bodies 2, 8, 11 form a little mass of gray matter. These are bound together with fine white connective tissue. Such a structure is known as a ganglion. Nerve fibers 10, 7, 1, and 6 are also united together by fine connective tissues

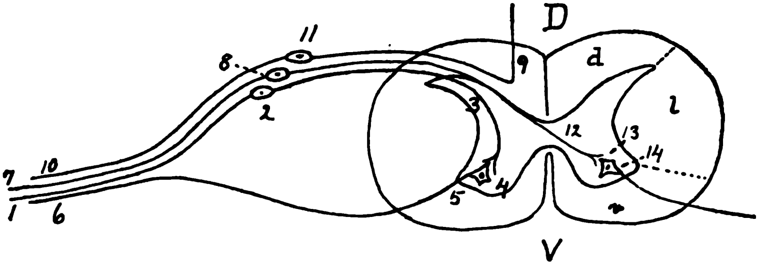


FIG. 76. — Diagram of cross section of spinal cord showing arrangement of the neurones. *D*, dorsal aspect; *V*, ventral aspect; *d*, dorsal, *l*, lateral, *v*, ventral columns of white matter. 11, 8, 2, cell bodies in dorsal root ganglion; 10, 11, 9, sensory fiber entering the dorsal column to continue to a higher level in the cord; 7, 8, 12, sensory fiber passing to ventral horn of opposite side; 1, 2, 3, sensory fiber to ventral horn of same side; 13, 4, synapses between sensory and motor neurones; 5, 6, motor neurone, completing with 1, 2, 3 a reflex arc; 5, 14, cell bodies of motor neurones.

and constitute a nerve. Several nerves may unite to form a nerve trunk. Here each axone remains perfectly distinct from all the others. It joins the group of axones, some of which may be sensory and some motor, and runs in their company for a time, and it parts from them but always retains its independence. The cross section of such a nerve trunk is seen in Fig. 77.

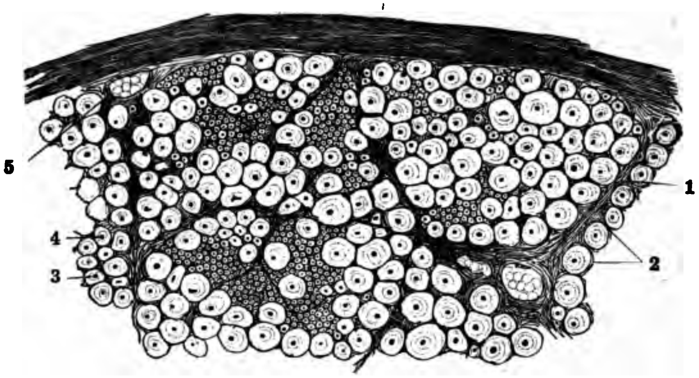


FIG. 77. — Cross section of a nerve trunk. 1, perineurium; 2, fiber sheath; 3, medullary sheath; 4, axone; 5, blood vessel containing corpuscles. (Stoehr.)

Let us turn our attention to the cross section of the cord again. In Fig. 76 was shown the cord and one of the spinal nerves. The neurones were such as are supplied to the skin and voluntary musculature, *i.e.* the afferent fibers are such as call forth not only reflex movement but also conscious sensation and the efferent fibers all pass to the voluntary muscles. If we are to include in our diagram the nerve supply of the viscera and blood vessels it will be necessary to make some additions to Fig. 76, such as are seen in Fig. 78. Here it is seen that the ventral root contains two sorts of neurones, 3 and 4, the latter running as in Fig. 76 to the voluntary muscles, the former running to a group of cell-bodies (ganglia) and ending in

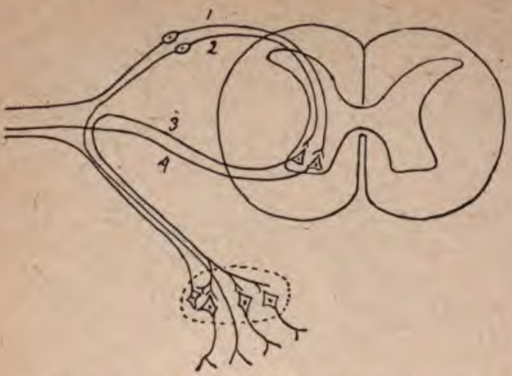


FIG. 78. — Diagram showing the relation of splanchnic and somatic neurones. 1, 4, sensory and motor somatic fibers forming a spinal nerve; 2, 3, sensory and motor splanchnic fibers leaving the spinal nerve by way of ramus communicans and passing to an autonomic ganglion where the preganglionic fiber, 3, is relayed by four postganglionic neurones. Three of the latter send axones directly to the viscera, while the remaining one sends its axone back to mingle with the somatic fibers and to be distributed with them. Note that the splanchnic sensory fiber is not relayed.

their vicinity. Along with the first group run the afferent fibers, represented by 1; with the second those represented by 2. The first group constitutes the spinal nerves, to which reference has already been made; the second, the autonomic nervous system which supplies the viscera, blood vessels, etc. It may be observed that the neurones 1 and 2 differ only in the destination, while 3 differs from 4 in that, though the latter passes directly to its end organ, the voluntary muscle, the former ends in a ganglion and its impulse reaches the end-organ only through a second group of

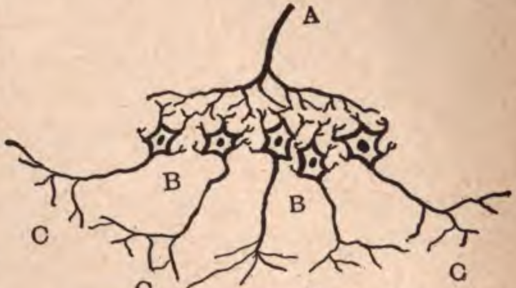


FIG. 79. — Diagram of autonomic ganglion showing how the impulses coming by way of a single preganglionic fiber, *A*, may be distributed and through connections with numerous postganglionic neurones, *B*, be spread over quite a considerable area, *C*.

neurones whose cell-bodies lie in the autonomic ganglion. (See Fig. 79.) The spinal nerves and the autonomic system are often called collectively the peripheral or outlying nervous system, while the spinal cord (with the brain) is known as the central nervous system. The ganglia of the autonomic system are, for the most part, connected longitudinally by axones which do not end in the autonomic ganglion which they first enter, but run forward and backward to end in some other ganglion.

If the student has fully grasped the idea of the structure of a single spinal segment as so far presented, she may be encouraged to know that she has acquired the fundamental facts in regard to the structure of the nervous system. She has merely to imagine thirty-two segments similar to that described and constituting the spinal cord, a half score or more segments bearing a strong resemblance to the spinal segments with two regions, cerebrum and cerebellum, in which more space has been gained for cell-bodies through the fact that the

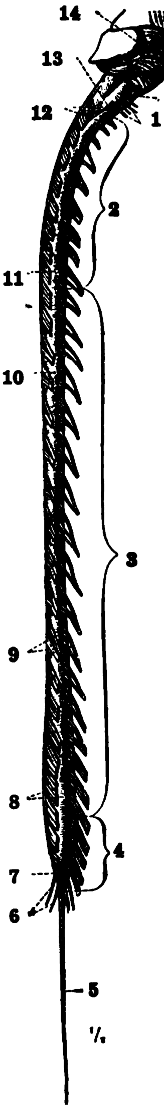


Fig. 80 *A.*—Spinal cord viewed from the right side. 1, root of the hypoglossal nerve; 2, cervical region of the cord; 3, thoracic region and lumbar region; 4, sacral region; 5, filum terminale; 6, roots of the coccygeal nerves, dorsal and ventral; 7, conus medullaris; 8, roots of the first sacral nerve; 9, of the first lumbar; 10, lateral column of white matter; 11, roots of the first thoracic nerve; 12, of the first cervical nerve; 13, root of the accessory nerve; 14, pons. (Toldt.)

gray matter is on the outside instead of the inside and that the surface area available is then vastly increased by the foldings[1] (convolutions) of this surface.

Spinal Somatic Nerves. — We have considered the typical spinal segment. Let us now see in what way the type is modified in different parts of the central nervous system. The somatic branches of the spinal nerves supply with motor fibers the voluntary muscles of the trunk and extremities and with sensory fibers, the skin, tendons and voluntary muscles of the same region. In the cervical region and again in the lumbar, the cord is enlarged owing to the fact that here are situated the cell-bodies and here emerge and enter the processes of the neurones which supply the

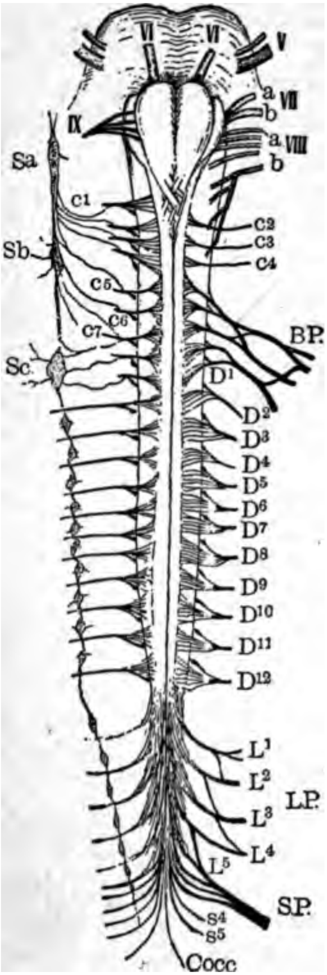


FIG. 80 *B.* — Base of brain, spinal cord and spinal nerves. *V*, trigeminal nerve; *VI*, abducens nerve; *VII a*, facial, *b*, acoustic nerves; *VIII a*, glossopharyngeal and vagus, *b*, accessory; *IX*, hypoglossal; c^1–c^7, cervical nerve roots; D^1–D^{12}, thoracic nerve roots; L^1–L^5, lumbar nerve roots; S^4–S^5, 4th and 5th sacral nerves; *Cocc*, coccygeal nerves; *B.P*, brachial plexus; *L.P*, lumbar plexus; *S.P*, great sciatic nerve arising from the sacral and lumbar plexuses; *S a, b, c*, cervical autonomic ganglia. (Kimber.)

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[1] It is interesting to compare this with the method of increasing the areas for secretion and absorption in the body, see page 230.

arms and legs, respectively. The spinal nerves in these regions undergo a more or less complex interlacing, fibers from one nerve trunk passing over and joining those of another before leaving the vicinity of the cord. Such an arrangement is known as a plexus. From the cervico-thoracic or -brachial plexus arise several large nerve trunks for the arm, from the lumbo-sacral plexus arise those for the leg, among which may be mentioned especially the great sciatic or ischiadic nerve (Fig. 80 *B*).

Cranial Somatic Nerves. — The somatic motor branches from the nerves which arise from the brain (cranial nerves) are distributed to the muscles of the head. The sensory fibers are of two kinds; those of which the function is similar to the corresponding spinal structures and which are distributed to the tendons, muscles, and skin, and secondly, the nerves of special sense, as they are called, which are distributed to the organs of hearing, taste, sight, position, and smell.

Taken in order from before backward, the cranial nerves have the following names and functions:

I. Olfactory nerve, or rather nerves, are a number of fine filaments which pass from the olfactory bulb through the perforations in the ethmoid bone (cribriform plate) and are distributed to the mucous membrane lining the nasal passages. The cell-bodies which correspond to the dorsal root ganglia of the spinal nerves are situated in the olfactory bulb and from them other fibers pass to the center for smell in the cerebral cortex.

II. Optic nerve, so called, is really an outlying part of the brain, and the cell-bodies which correspond to the dorsal root ganglia of the spinal nerves are situated in the retina of the eye. Part of its centrally running axones terminate in the same side of the brain, while the remainder cross to terminate in the similar region on the opposite side of the brain.

III. The occulomotor supplies all the muscles of the eye except the superior oblique and the lateral rectus.

IV. The trochlear nerve supplies only the superior oblique muscle.

V. The trigeminal, one of the largest of the cranial nerves, is both motor and sensory and its ganglion is known as the Gasserian or ganglion semilunare. The sensory fibers are distributed to almost every part of the head. The motor fibers are supplied to the muscles of mastication.

VI. The abducens nerve supplies motor fibers to the lateral rectus muscle of the eye.

VII. The facial is the motor nerve of all the muscles of the face, and of some belonging to the neck and ear. The facial is also a nerve for the special sense of taste. The taste fibers after passing over to the lingual branch of V. are distributed to the anterior two thirds of the tongue.

VIII. The so-called acoustic nerve has two distinct parts, the cochlear and the vestibular part. Both are sensory and have their cell-bodies (corresponding to the dorsal root ganglia of the spinal nerves) situated in the internal ear. The cochlear is the nerve of hearing, while the vestibular is the nerve of perception of the position and direction of motion of the head.

IX. The glossopharyngeal sends motor fibers to the muscles of the pharynx and sensory fibers to the mucous membrane of the tongue and pharynx. It also supplies the back part of the tongue with taste fibers.

X. The vagus nerve is chiefly composed of autonomic fibers. Its somatic functions and distribution are relatively unimportant.

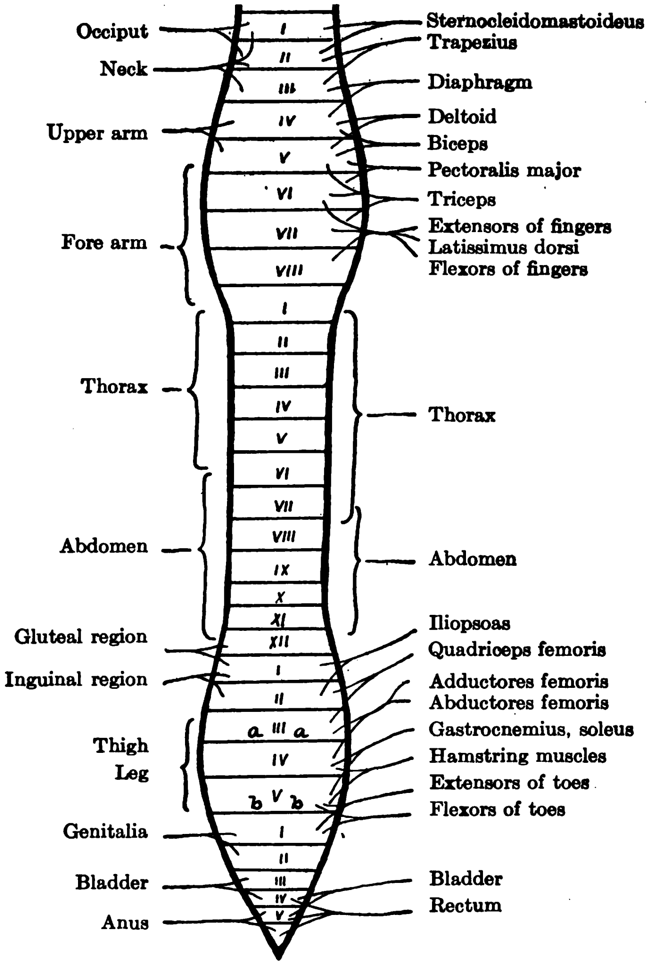

FIG. 80 *C*. — Diagram of the somatic fibers of the trunk, showing the origin of the efferent fibers from the cord and the entrance of the afferent fibers into the cord. The spinal cord is divided into four regions, cervical, thoracic, lumbar, and sacral. Within each region the spinal segments bear Roman numbers. On the left of the diagram the locality supplied by the sensory (afferent) neurones is indicated by one or more words and these latter are connected with the segments of the cord at levels at which the nerves enter. On the right side are the names of the muscles or groups of muscles and to them are drawn reference lines which start from the segment of the cord in which their cell-bodies have been located. Within the cord itself, the designations for several reflex centers are indicated in the segment where the mechanism is localized. *a*, patellar reflex (knee-jerk); *b*, reflex of the tendon of Achilles (tendo calcaneus). (Modified from Donaldson after Struempell and Jakob.)

XI. The accessory nerve is a motor nerve. It arises in part from the medulla and in part from the spinal cord. It supplies several of the neck muscles.

XII. The hypoglossal is a motor nerve for the tongue.

All the cranial nerves, from VI. to XII. inclusive, arise from the medulla with the exception of part of XI. as already stated.

Spinal Autonomic Nerves. — Turning now to the splanchnic or autonomic branches of the spinal nerves, we see in the spinal region an arrangement which is diagrammatically shown in Fig. 81. Each segment is seen to have a vertebral or "stationary" ganglion except in the cervical region where the

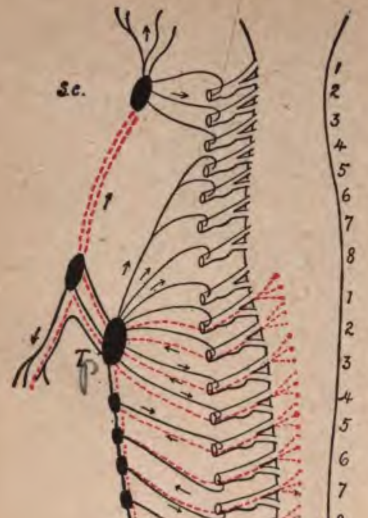

FIG. 81. — Diagram of the autonomic fibers of the trunk. The preganglionic fibers are represented in red; the postganglionic in black lines. The arrows indicate the direction normally taken by the nerve impulses. *S.c*, superior cervical ganglion; *T*, the first thoracic ganglion; *Sp*, the splanchnic nerve; *C*, the cœliac ganglion; *m*, inferior mesenteric ganglion; *h*, hypogastric nerves; *N.E*, nervus erigens. The numerals indicate the corresponding nerves. Only the splanchnic efferent fibers are represented. (Howell.)

vertebral ganglia are fused into two masses, the inferior (*T*) and the superior cervical ganglion, (*S.C*). Besides the vertebral ganglia there lie more peripherally other ganglionic masses (vagrant ganglia) which serve as points of distribution of the nerve fibers to the viscera. The autonomic fibers, that is, the fibers which supply the plain muscle of the blood vessels (vasomotors), the plain muscle of the hairs (pilomotors, which on contraction cause erection of the hairs as when one is cold and has " goose skin "), the remaining smooth muscle (visceromotors) and the cardiac muscle (cardiomotors) all pass out of the cord by way of the ventral nerve roots and enter the vertebral ganglia. Here some of them end and in this case the impulse is taken up by the second neurone (post-ganglionic neurone), the cell-body of which lies in the vertebral ganglion while its axone passes back to the spinal nerve; there it mingles with the somatic fibers, with which it runs for a time but leaves them finally to terminate in the walls of the blood vessels or the glands of the skin or the pilomotor muscles. On the other hand some pass through the vertebral ganglion to end in a vagrant ganglion, where the post-ganglionic neurone takes up the impulse and carries it to the muscular structures, blood vessels and glands of the viscera.

Cranial Autonomic Nerves. — The autonomics of the head arise from the third, seventh, ninth, and tenth cranial nerves. Here the distinction between the stationary and vagrant ganglia cannot be drawn with certainty. The relations of the structures in this region are shown in Fig. 82, which is fully explained in the legend.

Acquired Reflexes. — We are born with certain well-defined reflex paths, for example the reflexes concerned with the activity of the viscera, with respiration, circulation, and so forth. Certain other reflex paths are

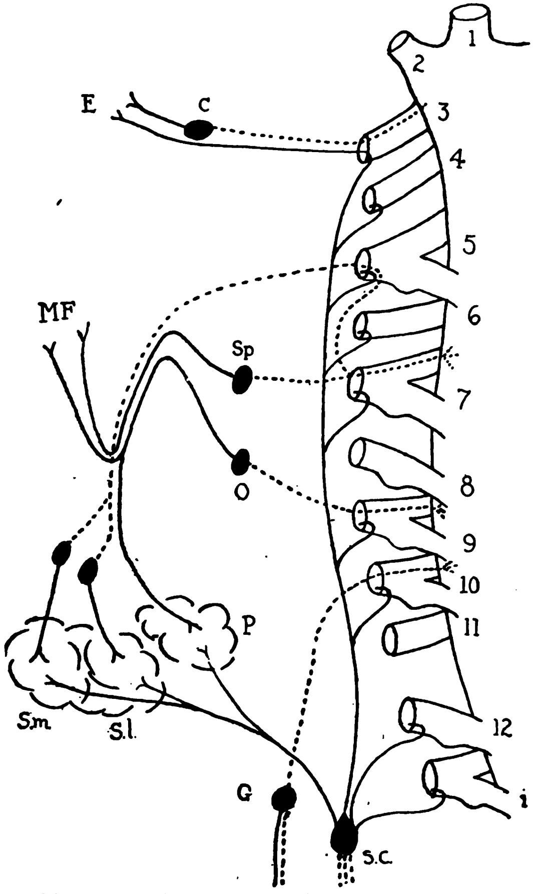

Fig. 82. — Diagram of the autonomic fibers of the head, both those arising from the cranial nerves and those coming by way of the superior cervical ganglion. The dotted lines represent pre-, the full lines post-ganglionic fibers. Superior cervical ganglion (*S.C*) sends branches to cranial nerves (vaso-constrictors and -dilators), to the salivary glands (*S.m*, *S.l*, *P*), vaso-constrictors and secretory fibers, also by way of the oculomotor (dilators for the pupil of the eye, *E*). Oculomotor sends fibers (pupilo-constrictors and ciliary motors) to the ciliary ganglion, *C*, and the eye. Facial nerve sends fibers, 1, (vaso-dilators) to the sphenopalatine ganglion (*Sp*), whence they pass by way of trigeminal to mouth and face; 2, (vaso-dilators and secretory) by the same route to submaxillary and sublingual ganglia and glands (*S.m*, *S.l*). Glossopharyngeal sends fibers to otic ganglion, *O*, whence they pass to the mouth and face (vaso-dilators) and to the parotid gland, *P* (vaso-dilators and secretory). Vagus sends fibers to the ganglion, *G*, to the thoracic and abdominal viscera.

acquired by practice, for example, the reflex of dancing to music, which involves the response of the foot to stimulation of the ear, or the reflex of writing at dictation, which involves the response of the hand to stimulation of the ear, or the reflex of catching a ball, which involves the response of the hand to stimulation of the eye. In all these examples the impulse starts from some sense organ, passes by a complex path through the nervous system and results in a definite appropriate response.

Our ability to acquire these and other skilled movements by practice, that is to convert by mere repetition an act which was once conscious and difficult into one which is subconscious and easy, has led to the belief that every impulse which traverses the nervous system leaves its path easier of travel for the next impulse. To use a phrase borrowed from the electricians, the impulse lowers the resistance of the path along which it travels. So long as the path remains well beaten and distinct, we can perform the skilled act in question. But with time and disuse these acquired paths or patterns gradually fade away, in other words, we forget.

The Cerebral Cortex. — It is the function of the subcortical parts of the nervous system to carry out reflexes be they simple or complex, inherited or acquired. What is the function of the cortex itself? To answer this question let us return to a consideration of the ball-catching reflex just referred to and learn how it may be modified by the introduction of the cerebral cortex into the nervous arc involved.

Let us suppose that our playmate at ball throws us, by way of a joke, a ball of mud, and furthermore that we detect the trick and decline the catch. What would be the character of the nervous reaction in this case? It would be essentially like the first reaction, that of the ordinary catch reflex, but more complex, for the nervous path would involve not only the arc of the catch reflex but also the neurone pattern, which is the physical basis of our concept of mud, a concept whose origin is worth considering.

Our concept of mud came into being in some such way as the following: One of the important objects in the early experiences of a child is mud. In the course of time he learns to associate certain properties so that they form a definite group. That which is dark, wet, sticky, mushy to the fingers, of a slight, peculiar odor, somewhat gritty to the taste, soils the hands and clothes and can be made into balls and pies is also called mud. Here we have a set of properties or sensations which form a peculiar group. If now at any time we see that which has the optical properties of mud, then the entire group of experiences, gustatory, tactile, and so forth, is aroused and we recognize the mud. Similarly we might recognize a friend by his walk or a bird by its song. The complete concept which is the product of past experiences and associations is recalled by the present partial experience of the object in question.

Now what happened when the mud ball was thrown to us was that two processes were started, namely the catch reflex and the process which underlies our recognition of mud, and as the result of the combination of the two processes the catch reflex was inhibited, the catch was declined. Here the *recognition* of the mud and the consequent inhibition of the catch reflex were mediated by the cerebral cortex.

All objects, facts, fancies, and what not so long as they can be recalled are represented in the cerebral cortex by neurone patterns of greater or less complexity. A moment's consideration will arouse our amazement at the enormous complexity of the cerebral cortex. If we were to write out *all* our memories, they would fill many, many volumes and yet they are all finding a place somewhere on the convoluted surface of the cerebral cortex.

The unconscious functioning of the sub-cortical parts of the central nervous system may be regarded as due to inherited memory, an inborn mechanism which governs our unconscious activities; just so our conscious and voluntary acts are the result of acquired memories, a mechanism developed through individual experience, which governs our conscious behavior. The unconscious reflexes have their physical basis in the neurone patterns of the subcortical regions of the brain and cord; while the conscious and voluntary activities have their physical basis in the neurone patterns of the cerebral cortex. Naturally the more highly developed the mental powers, the greater the complexity of the cortical basis, the greater the area of cortex required and consequently the larger the cerebrum and the deeper and more numerous the convolutions.

The importance of the cerebral cortex is also impressed upon us by the condition which results from its removal. Complete removal of the cerebral hemispheres has been accomplished in the case of a dog which survived the operation for eighteen months. After recovery from the operation, "the animal was able to walk in a perfectly normal fashion; . . . For the greater part of the day it walked restlessly up and down in its cage, but at night would go to sleep, rolled round in the manner usual with dogs. It then required a loud sound such as that of a horn, or a rough shaking to awaken it. When awake it reacted to loud sounds by shaking its ears, to a glare of light by shutting its eyes, and by turning its head away.

It reacted promptly and consequentially to tactile impressions. When its skin was pinched, it gave vent to its discomfort by snarling and barking just as a normal dog might do and attempted to get away from the hand which was the source of discomfort, or failing to do this would turn around and bite at it, but in a clumsy manner and often without coming near it. . . . The animal for months took no food spontaneously but had to be fed by placing food at the back of its mouth, and even then often choked in the process of swallowing. Eventually, it would take food if its head were placed over the dish containing it, and especially if the food came in contact with its snout. Meat which had been rendered bitter by quinine or colocynth was ejected with movements indicative of dislike. It also showed a feeling of satiety by refusing to take more than a certain quantity of food. For its size it required a very large amount of nourishment in order to keep up its weight; the extreme restlessness which it exhibited when awake tending apparently greatly to increase its katabolism. The higher psychical faculties were completely absent. The dog never showed any sign of recognition of persons or of other dogs; showed no fear of threatening movements; never wagged his tail, or showed any sign of pleasure at being stroked or spoken to; when wetted, shook himself vigorously but never attempted to lick himself dry as a normal dog does; never used his fore-paws to hold a bone or to dig a hole for one. . . . The animal showed no sign of memory. Although its removal from the cage was the usual signal for feeding, it invariably resisted being taken hold of for this purpose, barking loudly and biting and struggling vigorously. During sleep it never showed any indications, as dogs often do, of dreaming. It exhibited no sexual instincts."

Cerebral Localization. — We saw that in the case of the spinal cord certain patterns or arcs were definitely located, *e.g.* the center for the knee-jerk, and we shall see later that many other centers are definitely located, as the respiratory center with its afferent and efferent nerves and the vaso-constrictor center. Is there a similar localization in the cerebral cortex? Can we say for example that in this part of the brain lies the nervous representation of mud, in that of horse, and in the other of bread? Not exactly, but still there is localization of function in the cortex for all the memories of things seen lie in one region, of things heard in another, of things felt in another and so forth, and between these well understood areas there are areas which are but little understood but which we believe to be occupied by the connections between the known areas. If the concept of bread, for example, had a definite location in the cortex, it would seem possible that by slicing away the cortex in the proper place, we would slice off the memory of bread, so that the victim of this operation would no longer recognize bread. Now although we do not slice off people's cortices, various diseases and injuries perform similar experiments for us, with the result that the memory of bread is never lost except as part of a more extensive derangement. Such disturbances as are here referred to are the so-called cortical sensory paralyses or agnosias and the cortical motor paralyses. The light which these conditions throw upon the normal functions of the cortex is so great that, although this is not a textbook in pathology, a brief reference to these conditions seems justifiable.

It has been said that we cannot cut out the memory of bread but that we can cut out the visual memory of everything. If the occipital region of the cortex be destroyed, we suffer from cortical blindness, that is inability to recognize things seen. Bread, soap, handkerchiefs, all look equally strange, and to be recognized they must be approached with other senses than sight, as by touching or smelling them. In other cases it may be the auditory memory that is lost, as with lesions of the temporal lobes. In still others the tactile memory may suffer. These conditions are the agnosias.

On the other hand the power of recognition may be intact but our voluntary responses may be entirely lacking owing to a defect of the motor memories of the cortex. In the case of the motor representation in the cortex, it will be seen that the localization is very precise (Fig. 83). The memories of how to move the head, arms, trunk, and so forth are all situated in special subdivisions of the motor area. When this region is injured, the only possible

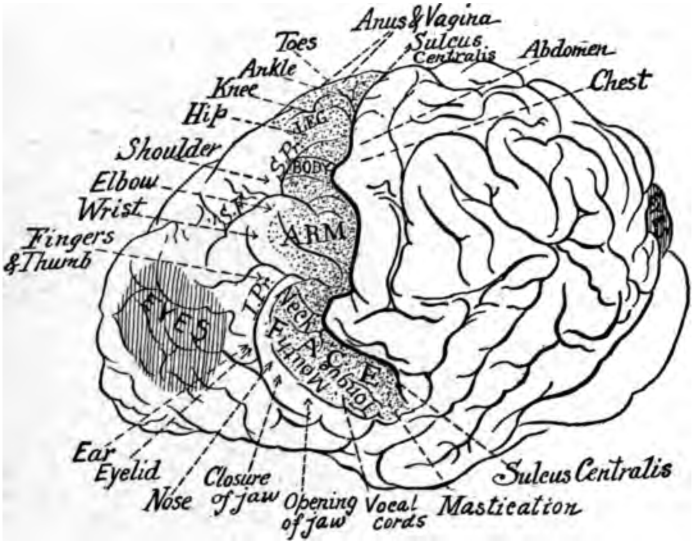

FIG. 83. — Location of motor areas of brain of chimpanzee. Dotted portions of the figure represent the cerebral motor areas. (Sherrington and Greenbaum.)

movements remaining to us are reflex. Our movements cannot be influenced at all by what goes on in the cerebral cortex, for there is no direct connection of the sensory areas of the cortex with the musculature but only by way of the motor memory area of the cortex.

Aphasia. — Among the most interesting nerve patterns, most elaborate and quite peculiar to human beings, are those associated with the use of language. Disturbances of these patterns go under the general name of aphasia, which may be motor or sensory. In one form of motor aphasia known as aphemia there is inability to name objects. This is to a certain extent a familiar failing. We speak not infrequently of what-do-you-call-it or what's-his-name. But in bad cases of aphemia the power of speech may be entirely lost or only a few words may be retained, although there is no cortical paralysis of the muscles used in speaking, which can be used for everything except speech. A second form of motor aphasia is agraphia, the inability to write. Here the individual loses his power of writing. He can perhaps read writing and perhaps copy writing, but although when he sees a ball he can say " ball," he cannot write the word.

On the other hand, there are the sensory aphasias. In " word deafness," for example, certain words or all words lose their meaning. We say " ball," to the individual but he has no more idea what we mean than though we spoke in Chinese. In still other cases the individual will know what we mean when we say "ball " but it is impossible for him to read the word when written — he has become illiterate. These various disturbances involve different areas of the cortex, for the functions referred to have definite location. Figure 84 shows the regions affected in the various forms of aphasia.

In conclusion, then, when we look for the localization of a concept as bread in the cortex, we find that it is represented in part in all the sensory areas of the brain. We also find that if the person can understand words, speak, read and write, then there are added a second set of areas in each of which there is a partial representation of the linguistic concept of bread. The entire concept is in both cases made up of adding together bits of widely scattered areas. Finally we see that the difference between the simple catch reflex and the declined mud ball consists in this, that in the latter case the impulse from the eye spreads over the cortex, traversing a wide-meshed net, and gathering itself together again in the motor area it descends to inhibit the catch reflex, which, if the cortical processes are quick enough, it succeeds in doing.

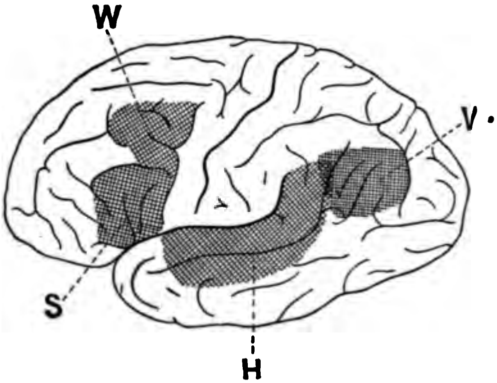

FIG. 84. — Areas affected in various forms of aphasia. *V*, visual; *H*, auditory memory for words; *W*, and *S*, motor memory for writing and speech, respectively. (Donaldson.)

The Cerebellum. — The functions of the cerebellum are only imperfectly understood. It seems probable, however, that it contains the sensory memories of the position of our bodies as a whole and of the relation of each part to all the rest. It must be remembered that all our larger movements require complex adjustments to meet the demands of equilibrium. It is not enough for a given stimulation to cause a flexion of the leg; the whole body must be readjusted so that the individual shall not lose his balance while making the movement in question. The belief that this readjustment is to be attributed to the cerebellum is supported by the fact that the fibers of muscle sense end there as also the fibers from the vestibular nerve, and by the effect of removal or disease of the cerebellum, which is characterized by a loss of muscular coördination.

Cortical Connections. — We have considered the functions of the cerebral cortex and of the cerebellum. Let us now see the connection of these structures with the rest of the central nervous system (the cord and brain stem). These relations are shown schematically in Fig. 85. The meaning of this figure can best be grasped by such examples as the following:

Suppose an odorous cheese be placed before an individual. The particles of cheese reach the nose, stimulating (*I*); the impulse passes to the cortical center (*S*) and the individual becomes conscious of the smell. This center is connected not only with the motor area (*M*), as shown in Fig. 85, but also with the other sensory areas in the cortex (connection not shown in Fig. 85). Visual, gustatory, tactile, and other memories are aroused which together represent to the subject the concept of cheese and which together act through their connection upon the motor cortex. The excitation of the motor cortex starts an impulse down the brain stem to the neurones which supply the eye muscles and the muscles which move the head. At the same time impulses are passing from the vestibule and semicircular canals (the organ of position and motion of the head), the fibers of muscle sense (sense of position and motion of the muscles), the former by the eighth cranial nerve, the latter by the somatic afferent fibers of several cranial nerves and of the spinal nerves, to the cerebellum (*Cbl*), and from the cerebellum (*Cbl*) to the red nucleus (*R.N.*), and thence the course of the impulses is parallel to those descending from the motor cortex of the

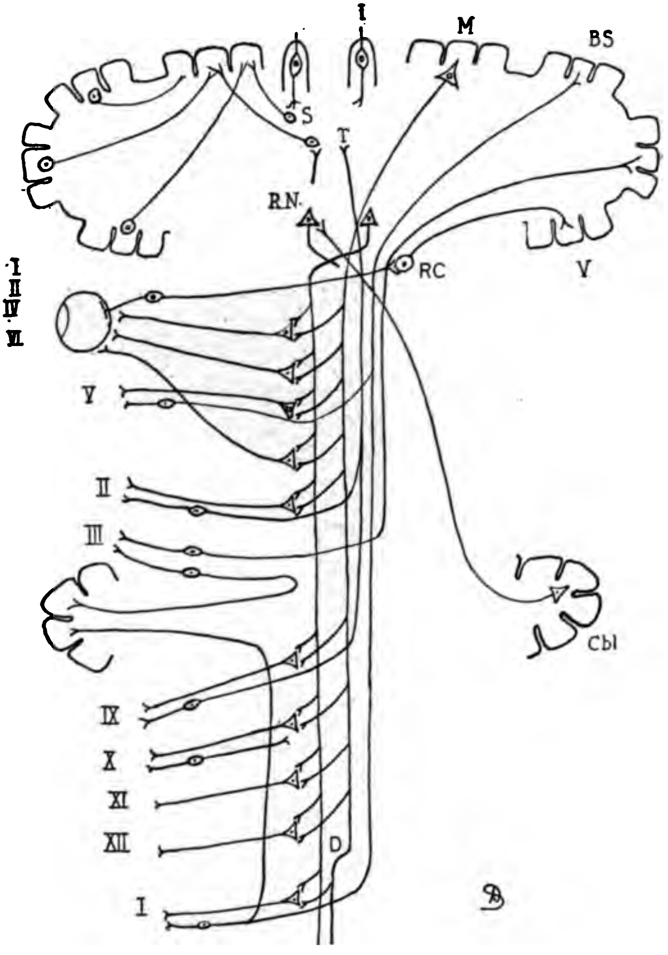

FIG. 85. — Diagram showing relation of cerebral and cerebellar cortices to cranial and spinal nerves. *I* to *XII*, cranial nerves; first spinal nerve is also represented. Cell-bodies of sensory neurones are drawn oval, of motor neurones angular. *S*, center for smell; *T*, for taste; *BS*, for skin and muscular senses; *A*, for auditory; *V*, for visual; *M*, motor center. *Cbl*, cerebellum; *R.N*, red nucleus; *RC*, reflex center; *D*, crossing of motor tract.

cerebrum. The two sets of impulses reach the neurones which control the movement of the eyes and head and the eyes and head are moved until the individual sees the cheese. If it were not for the impulses from the cerebral cortex no movement at all would occur. If it were not for the impulses from the cerebellar cortex, the movements would be badly coördinated and ineffective.

An omission in Fig. 85, made to avoid complexity but to which attention should be called, is this: The sensations from the eye are shown to pass to a lower center before being relayed to the cortex. This center is a reflex center. It connects with the motor paths in such a way that many actions may occur without the participation of the cortex. The other sensory paths shown in Fig. 85 are also interrupted in the same way, although these interruptions are not represented in the figure, and any afferent impulse may fail to reach the cortex and result only in reflex motor responses.

CHAPTER VI

THE SENSES

THE sensory or afferent neurones, which have their cell-bodies in the dorsal root ganglia, terminate in the periphery in ways which render each of them susceptible to one at least of many sorts of environmental changes. Ether vibrations, such as heat and light; air vibrations, such as sound, and various forms of mechanical pressure and chemical action all affect the organism through the mediation of these afferent neurones. These neurones are of two sorts (1) those which affect the cerebral cortex, *i.e.* give us conscious sensations, (2) those which act entirely subcortically, *i.e.* reflexly. The second group will be considered in connection with the various reflexes of which they form the afferent limb; the first group comprises the fibers of cutaneous and subcutaneous sensation and also the fibers of vision, of smell, of hearing, of position, and of taste.

Cutaneous, Subcutaneous, and Visceral Sensibility. — The skin is supplied with two sets of nerve fibers known respectively as epicritic and protopathic; the latter seem to be the more primitive. They give us sensations of (1) pain, (2) heat (above 37° C.), (3) cold (below 26° C.). Their sensibility is low, their localization (p. 123) poor, and they regenerate more quickly than do the epicritic fibers. The epicritic group contains fibers which give us sensations of (1) light touch — as distinct from pressure, (2) small differences of heat, (3) small differences of cold. Epicritic sensibility is confined to the skin, but protopathic sensibility is also present in the viscera.

The deeper tissues are supplied not only with the

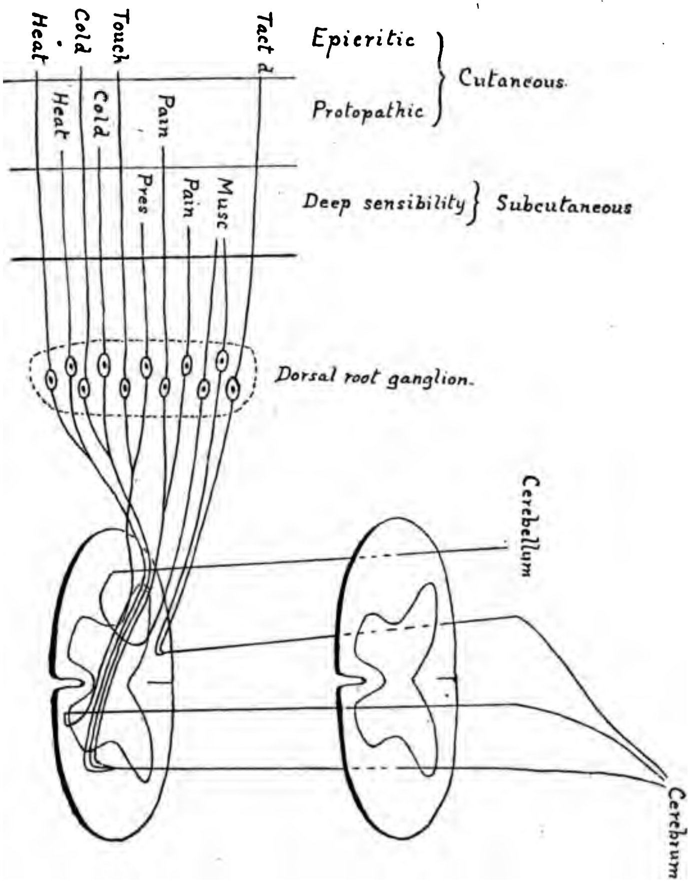

FIG. 86. — Diagram of course of cutaneous fibers on reaching the cord.

protopathic fibers already mentioned, but also with fibers which give us a sense of pressure and in the case of the muscles and joints with fibers which give us a knowledge of the position of the various movable parts of the body (muscle sense).

The fibers which exhibit the various functions above described do not follow the same path in their journey through the central nervous system. It is therefore possible at times to determine the position of an injury of the cord by noting the forms of sensibility which are affected, since the injury must be so located as to interrupt the paths of the sensations affected. Figure 86 shows which paths cross to the opposite side of the cord after entering it and which paths continue their upward course on the same side of the cord as that on which they enter.

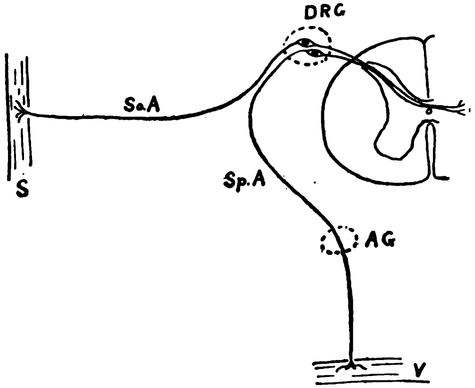

FIG. 87. — Diagram showing mechanism of referred pains. *So.A*, a somatic afferent neurone; *Sp.A*, a splanchnic afferent neurone which enters the same segment of the cord as *So.A*, and which has its cell-body in the same dorsal root ganglion (*DRG*) as *So.A*. *So.A* ends in the skin; *Sp.A* ends in the viscera, *V*. *AG*, autonomic or splanchnic ganglion, whether vertebral or vagrant, through which *Sp.A* passes without interruption. *So.A* and *Sp.A* being in the same segment, it often occurs that when a stimulus is applied at *V* (an unusual event), it is judged to come from *S* (whence impulses are often received). For example, irritation of the intestines is felt as pain in the area of skin distribution of the thoracic nerves IX, X, and XI, that is in the skin of the back, loins, and abdomen. So also in heart disease the pain is felt in the scapular region; irritation of the stomach in the skin over the lower end of the sternum; eye strain in the skin of the supra-orbital region (p. 50).

Referred Pains. — Not only are the viscera rather scantily supplied with sensory fibers, but our ability to localize pain in these regions is very imperfect. Not infrequently a visceral pain is referred to an entirely wrong place. This misreference of visceral pain is not, however, a chance and lawless matter. For, if it is not felt in the viscus where the stimulus is actually applied it is referred to, that is, appears to come from, the cutaneous area to which is distributed the somatic sensory fibers of the same spinal segment as the autonomic afferents which are stimulated (Fig. 87). Of the sensory fibers enumerated above two only require especial comment, namely, the fibers of muscle sense and the fibers which mediate not only the sense of touch but are also concerned with " tactile discrimination."

Muscle Sense. — We are all aware of the position of our arms and legs. We can form an excellent mental picture of the way in which we are posed even when our eyes are shut, but under certain conditions this knowledge may be very imperfect and quite inadequate for the needs of ordinary life. A diseased condition of the dorsal white matter of the spinal cord is called from its most important sign "locomotor ataxia," lack of coördination in locomotion. Here the fibers of muscle sense ending in the joints, tendons, and muscles no longer send the patient the impulses derived from the various pulls and pressures which are different for every position of the body. The patient is no longer able to perceive the position of his own limbs and consequently the coördination of his musculature is very imperfect.

Tactile Discrimination. — It is common knowledge that we distinguish between a touch applied to the hand and one applied to the back of the neck. The touch stimulus may be the same, but the part stimulated is different. This difference we call the " local sign " and the power to distinguish between different points stimulated is known as " tactile discrimination." The acuity of tactile discrimination is tested by means of a pair of compasses, it being the task of the observer to find out how far apart the points of the compasses must be before they are recognized as two distinct stimuli. For example, in the finger the acuity or tactile discrimination is great, the compass points need be only 0.25 cm. apart to be felt as two, while on the back the acuity is dull, for if the compass points are less than 6.75 cm. apart, the subject cannot distinguish the local signs of the two points but believes that he has been touched at one point only.

The power to distinguish between local signs, that is, tactile discrimination, is of course dependent upon the power of detecting a touch. One cannot distinguish between two points which cannot be felt at all, but on the other hand, the power to localize the point touched may be absent, although the power to feel that the skin has been touched somewhere persists unchanged. In Fig. 86, we see that the fibers which mediate the sense of touch and those of tactile discrimination together occupy both sides of the cord, on their way to the cerebral cortex. Consequently the sense of touch is impaired by cutting halfway through the spinal cord, but is not lost unless the cord is completely severed. On the other hand, such a " demisection " of the cord destroys tactile discrimination on the same side of the body as the demisection.

Punctiform Distribution. — The sensory nerves are not present in such numbers in the skin that the areas to which they are distributed overlap. In fact they leave some space between them so that it is not difficult to find a region between the areas of distribution to two adjacent pain fibers, for example, which is quite devoid of pain sensation. In other words, the distribution of sensation upon the skin is punctiform; there are pain points, heat and cold points or areas, supplied by a single neurone, between which are insensitive spaces (Fig. 88).

Taste. — The fibers which mediate the sensation of taste are distributed to various parts of the buccal cavity, especially to the surface of the tongue. They end in little groups of sensory epithelial cells known as taste-buds (Fig. 89). These epithelial cells are stimulated by the chemical action of the substances tasted. From them the sensory impulses pass to the central nervous system by two paths. From the anterior two thirds of the tongue the impulses pass to the medulla by way of the ganglion of the facial nerve or by way of the semilunar ganglion of Gasser of the fifth cranial nerve, or by both paths. The fibers which supply the posterior one third of the tongue

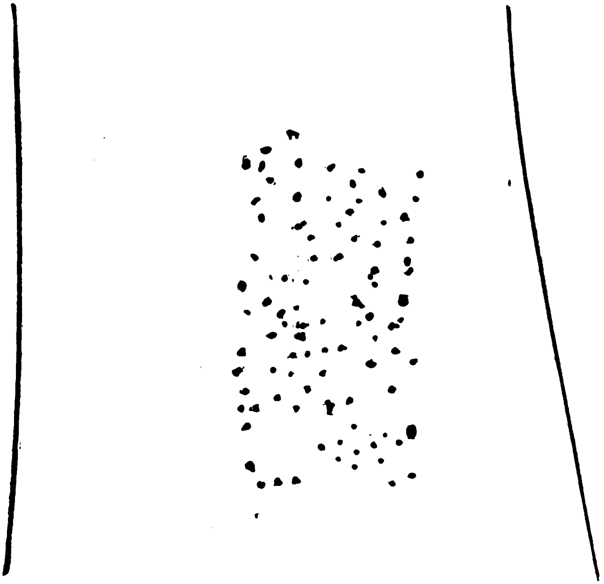

FIG. 88. — Diagram showing punctiform distribution of sensory nerve endings. Here are shown the cold and warm spots on the volar surface of the forearm in a space 2 X 4 cms. The red dots represent the cold spots as tested at a temperature of 10° C. The black dots represent the warm spots as tested at a temperature of 41° to 48° C.

carry their impulses to the medulla by way of the ganglion of the hypoglossal nerve or by way of the semilunar ganglion or by both paths. The varieties of sensations of taste appear to be more numerous than they actually are, owing to the fact that what we call a taste is often actually a combination of a taste with an odor. This fact becomes evident when, though the power of tasting remains normal, the sense of smell is lost, as in persons suffering from cold in the head. There are four varieties of taste sensation, namely, sweet, salt, acid, and bitter.

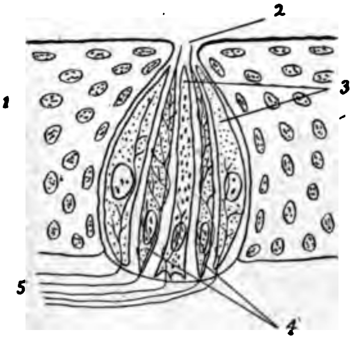

FIG. 89.—Taste bud, diagrammatic. 1, mucous membrane of the mouth; 2, taste pore; 3, sustentacular or supporting cells; 4, neuro-epithelial cells, with hair-like processes projecting toward the pore; 5, nerve fibers running in the submucous connective tissue, entering taste bud and wrapping themselves about the cells, especially the neuro-epithelial cells.

Smell.—The dendrites of the neurones which mediate the sense of smell end upon the surface of the mucous membrane of the upper part of the nasal cavity (Fig. 90). Unlike the neurones of taste the cell-bodies are not collected together into one or more distinct groups, but are scattered in the membrane itself. From these cells axones pass through the cribriform plate of the ethmoid and terminate in the olfactory bulb of the brain.

The mechanism of smell is simple. Odoriferous substances emit particles usually in gaseous form. These are carried by the currents of air to the mucous membrane of the nose where they become dissolved in the secretion of the membrane, and act chemically upon nerve-endings. It is a matter of common observation that the sense of smell may be extraordinarily delicate. It soon becomes fatigued, however, so that odors which may at first have been almost overpowering soon cease to be detected at all.

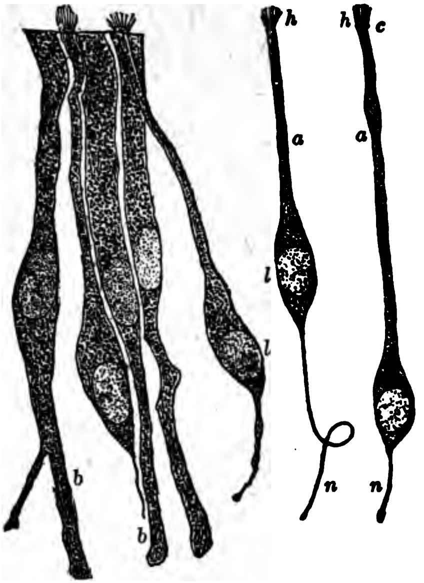

FIG. 90. — Cells of the olfactory region. *a*, *a*, olfactory cells; *b*, *b*, epithelial cells; *n*, *n*, central process prolonged as an olfactory nerve fiber; *l*, *l*, nucleus; *c*, knob-like clear termination of peripheral process; *h*, *h*, bunch of olfactory hairs. (v. Brunn.)

Optics. — It is a matter of common knowledge that rays of light in passing through a convex lens are bent (refracted) and brought to a point. In Fig. 91 the rays of light from a point *P*, which fall upon a lens *L*, are represented by lines all of which (except the one which passes through the center of the lens) are bent so that they meet at a point *F*, the focus. It is obvious that the nearer *P* is to *L* the farther *F* will be behind the lens and conversely the farther *P* is from *L* the nearer *F* will be to *L*. Again if we increase the convexity of the lens, thereby increasing its refractive power, the point *F* will move nearer to the lens (Fig. 92), and conversely if we decrease the convexity of the lens, the point will move away from the lens.

It is obvious that as *P* moves away from *L*, the lines which represent the light streaming from *P* will become more and more nearly parallel. When *P* has reached a point which is infinitely distant from *L* the rays which come from it will be exactly parallel. These parallel rays will be focused as usual by the lens. The focal point for parallel rays has a special name. It is called the principal focus. Now as *P* approaches *L*, coming in from the position infinitely remote from *L*, the focus of the rays from *P* will gradually move away from the principal focus and away from the lens. At first, however, this movement is very slight, and in the case of the eye it is not until *P* is within a short distance of the eye (six to ten meters) that the position of the focal point changes perceptibly.

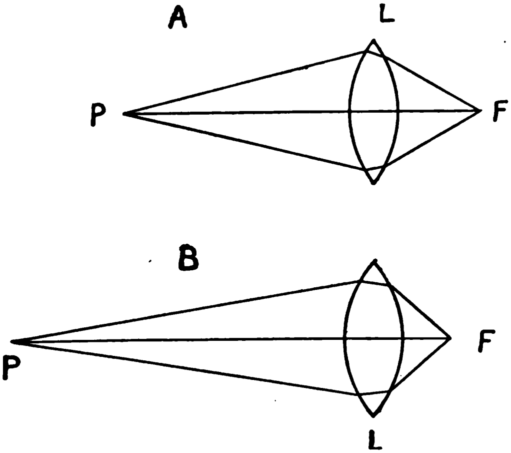

FIG. 91. — Diagrams: effect of double convex lens on rays of light. *P*, source of light; *F*, focus. On inspection of *A* and *B* it is evident that the nearer *P* is to *L* the further *F* is from *L* and vice versa. When *P* is infinitely remote so that the rays are parallel the point at which the rays are brought to a focus is known as the principal focus.

Suppose instead of a single source of light we have several such sources, or, what amounts to the same thing, suppose we have not a point of light but an object. The rays of light proceeding from each point of this object will be focused in a series of corresponding points behind the lens (Fig. 93). If, as in the case of the camera, a ground glass plate be so placed that the foci of all the points of the object shall be upon it, we obtain an image of an object. If the ground glass be replaced by a sensitive plate, we get a permanent picture. If instead of a camera we have the eye, then when the image falls upon the retina we see the object. If the screen is too far from the lens the image is blurred. The same effect is produced when the screen is too near. This is owing to the fact that, in these cases, the points of the object are not represented as points on the screen but as disks of light. These disks over-lap and produce a confused image. The same is true in the case of the eye. If the retina is too near the lens or too far away from it, our

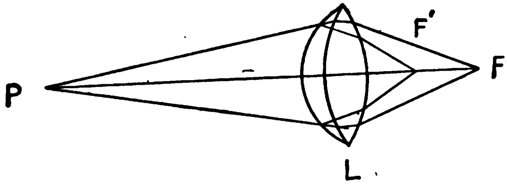

FIG. 92. — Diagram showing effect of varying convexity of lens upon the focal point. The stronger (more convex) the lens, the shorter the focal distance, that is the nearer the focus to the lens. In accommodation an image which the lens of the resting eye would bring to a focus behind the retina is moved forward by increasing the convexity of the lens until the focus comes to lie upon the retina.

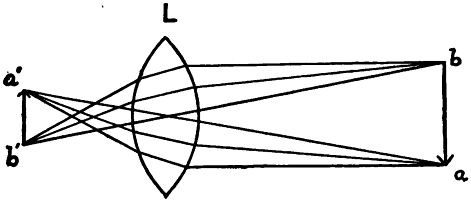

FIG. 93. — Diagram showing formation of image. *a* and *b* are two points of an object, *ab*. Each of these points sends out a pencil of rays which passes through a lens (*L*) and are brought to a focus at *a'* and *b'* respectively. If *ab* be considered as a succession of points, then for each of these there is a corresponding point between *a'* and *b'*. Similarly any series of points (any object) is brought to a corresponding series of foci on the retina.

vision is blurred. In the normal resting eye (called the emmetropic eye) the distance from the lens to the retina is such that the latter lies at the principal focus of the lens (Fig. 94, 2). Hence objects which send to the resting eye rays which are parallel or nearly parallel are clearly seen. If, however, the object is moved to a point, say 50 cm. from the eye, the object is no longer brought to a focus at the principal focus, *i.e.* on the retina, for now the retina lies inside the focus, in other words it is too near the lens.

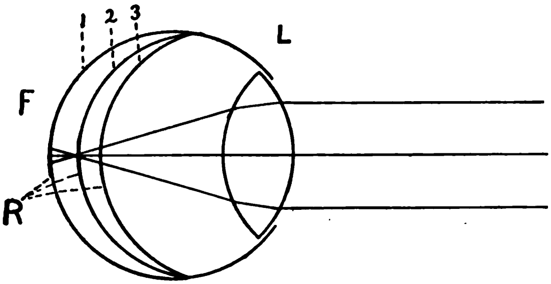

FIG. 94. — Diagram illustrating emmetropia (2), myopia (1), and hypermetropia (3). *L*, lens; *F*, focus; *R*, retina in three positions above mentioned.

To provide for this condition the eye "accommodates" itself to this change in position of the object. This is not by moving the retina back but by increasing the convexity of the lens, thus bringing the image forward. How this change is brought about in the lens will be discussed later. Objects farther off than 100 cm. can be seen without accommodation, but for objects nearer we must increase the convexity of the lens, that is, accommodation is necessary.

In the normal resting (*i.e.* unaccommodated) eye with the object not nearer than 1 meter the image falls upon the retina. But how about the abnormal eye? Obviously the eye may be either too long or too short (Fig. 94). If it is too long the retina lies behind the principal focus (a condition known as myopia). An object which is 1 meter away would be only indistinctly seen, for its image is at the principal focus which is in front of the retina. To throw the image farther back so that it may come to lie on the retina, it is necessary to bring the object nearer, and the longer the eyeball the nearer must the object be brought before it becomes distinctly seen. This is short-sightedness.

If, on the other hand, the eyeball is too short, the image of an object 1 meter or more away falls behind the retina (hypermetropia). Then in order to see clearly the image must be brought forward by increasing the convexity of the lens, *i.e.* by accommodation. Now the eye is capable of only a certain amount of accommodation. If it is necessary to accommodate for objects one or more meters away there is naturally but little power left to accommodate for objects which are nearer than 1 meter. Thus, though far objects can be seen (by means of accommodation) near objects cannot be seen at all. These defects in the formation of the eye can be corrected by spectacles, and a very little consideration on the part of the student will make it evident that convex glasses

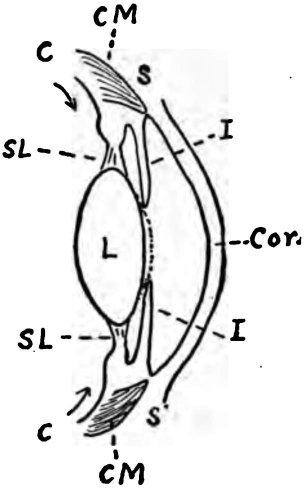

FIG. 95. — Diagram showing mechanism of accommodation. Section through anterior part of eye. *Cor*, cornea; *I*, iris; *S*, sclerotic, the backward continuation of the cornea; *C*, choroid, the backward continuation of the iris; *SL*, suspensory ligament; *L*, lens; *CM*, ciliary muscle. The ciliary muscle runs from a fixed point at the junction of the cornea and sclerotic to the choroid coat of the eye which is not so fixed. Contraction of the ciliary muscle therefore pulls the choroid in the direction of the arrows and thus relaxes the suspensory ligament. This allows the lens to return to its natural shape, *i.e.* to bulge more or less, especially on its anterior surface as indicated by the dotted line in the figure.

will be used in hypermetropia and concave glasses in myopia.

Accommodation. — Let us now consider briefly the process of accommodation, to the results of which attention has already been called. The lens of the eye is enclosed in a capsule which is attached all around its circumference by a ligament to the eye wall. The ligament is so tightly drawn that the lens is always compressed or flattened so that its focal length is less than it would be if it were without its capsule. If the "suspensory" ligament be relaxed, the lens will be relieved of its compression and will bulge, thus becoming more convex than before. The amount of increase in convexity will depend upon the degree to which the sus-

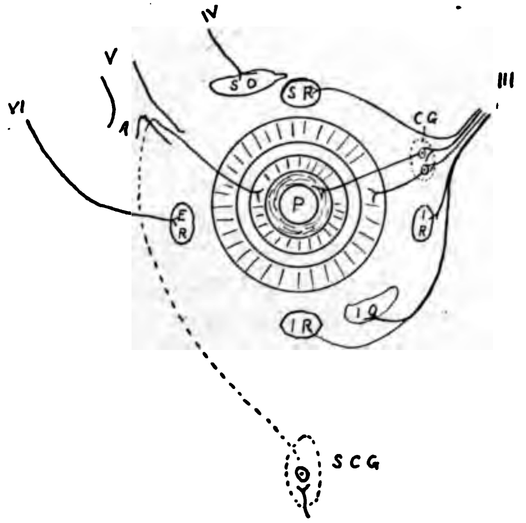

FIG. 96. — Diagram showing the nerve supply of the eye. *SO*, *IO*, superior, inferior oblique muscles; *ER*, *SR*, *IR*, IR^1, external, superior, internal, inferior recti; *P*, pupil; *SCG*, superior cervical ganglion receiving pupilodilator fibers from the spinal cord and transmitting their impulses by means of a post-ganglionic neurone (shown throughout most of its course as a dotted line). *CG*, ciliary ganglion. *III*, oculomotor nerve supplying *SR*, *IR*, *IO*, *IR* and, through the intervention of the ciliary ganglion, the ciliary muscle and the constrictor of the pupil. *IV*, trochlear nerve supplying *SO*; *V*, trigeminal nerve receiving the fibers from the *SCG* and transmitting them to the dilator muscle of the pupil; *VI*, abducens nerve supplying the external rectus. Around the pupil are represented from within outward the constrictor of the pupil, the dilator of the pupil, and the ciliary muscle.

pensory ligament is relaxed. Figure 92 shows the effect of accommodation in causing the rays from a near object to be brought to a focus upon the retina. Figure 95 shows the mechanical device whereby the ciliary muscle relaxes the suspensory ligament.

The Pupil. — Besides the ability to alter the power of the lens, the eye can also change the diameter of the aperture through which the light enters. In strong light the aperture is, to use the expression so common in photography, "diaphragmed down." The mechanism for controlling the size of the pupil is a double one. It consists in two sets of muscle fibers arranged about this aperture, the one radially so that on contraction they cause a dilation; the other arranged circularly and consequently causing, when it contracts, a narrowing of the pupil. The nerve supply (innervation) of these two muscles, as well as that of the ciliary muscle, is shown in Fig. 96.

Retina. — We have seen how the image of an object may be thrown upon the back of the eye just as the image of an object is thrown upon the sensitive plate of the camera. We shall now consider the nature of the structure upon which the rays of light fall, the membrane lining the back part of the cavity of the eyeball, known as the retina.

The retina is not a simple sensory surface like the skin of the hand, for instance. It is made up of elements which correspond to the dorsal root ganglia and the dendrites and cell-bodies of the first neurone of the cord. The retina, therefore, represents a combined structure consisting of both peripheral and central nervous structures (Fig. 97). The light which falls upon the retina sets up chemical changes in the sensory epithelium (rod and cone cells). These chemical changes in turn arouse nerve impulses which pass from neurone I to neurone II and thence along the axone of neurone II by way of the optic nerve to the brain. Here the nerve makes connection for reflexes. Thence the sensory path is continued to the cortex of the occipital lobe of the cerebrum. When it reaches the latter region, we become conscious of the object as seen. If this region of the cerebral cortex be destroyed, we no longer see, still light falling upon the retina will cause certain reflex reactions. For example, if the eye be exposed to strong light the pupil contracts. This is a reflex and the path of the impulse does not involve the cortex and it therefore persists after the cortex is destroyed. If, however, the optic nerve is injured, the reflex immediately disappears.

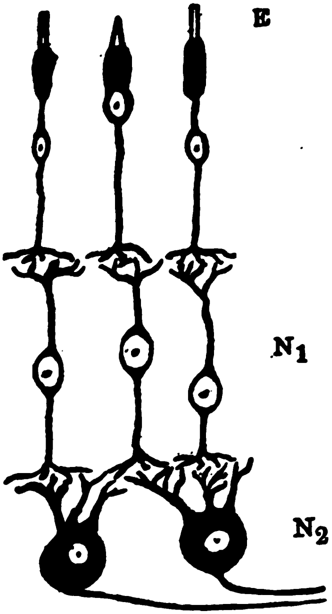

Fig. 97.—Diagram showing relations of neurones and epithelium in retina. *E*, epithelial layer of nucleated rod and cone cells, rods and cones being directed toward the exterior of the eyeball; N_1, neurones of the first series receiving through their dendrites impulses from the rod and cone cells and transmitting them through their axones to N_2, the neurones of the second series. The axones of the neurones of the second series pass along the retina to the blind spot, where they unite to form the optic nerve.

Color.—Besides being able to distinguish between light and darkness, between the different shades of gray, most persons distinguish between colors, red, blue, green, etc. The physical basis of light is the ether wave and that of color is the length or rapidity of the ether wave. Rapid waves produce in us the sensation of violet; slow vibration, of red, and between the two extremes we distinguish indigo, blue, green, yellow, orange, and many intermediate shades. This power of distinguishing between ether waves of different lengths seems to reside in the retina, but the exact mechanism which is involved is not known. The power may, however, be absent either totally or in part, leading to the condition known as color blindness.

The Fovea. — The part of the retina upon which the image falls when we look directly at the object with both eyes is more highly developed than the rest of the retina. It is there that our color perception and our acuity of vision are greatest. This region is known from its shape as the fovea centralis, the central depression.

The Blind Spot. — The retina is especially adapted for stimulation by light, just as the receiver of the telephone is especially adapted to respond to sound waves. As no amount of talking to the telephone wire will impress a message upon it, so light shining upon the optic nerve will be quite ineffective. The spot, therefore, at which the optic nerve emerges from the eye is insensitive to light and is known as the blind spot. Objects whose images fall upon this region fail entirely to arouse impulses or produce light sensation.

Sense of Solidity. — It might seem that a picture of an object and the object itself would cast exactly the same image upon the retina and yet it is not difficult to distinguish between a picture and an object. The artist may have made some objects small and indistinct and the others large and clear. If so, we recognize that the latter are intended to represent near objects but still we are not deceived into the belief that the picture has depth. The artist may have used mathematical perspective and made certain lines converge toward the "vanishing point" in the distance like the rails of a track down which we are looking. His effort to depict solidity may be very painstaking and yet one is not deceived.

There are three very essential differences between the external world and a painting of the same. (1) Whether one looks at a picture with the right or left eye makes no difference at all. But if one looks at solid objects first with one eye and then with the other, one finds a considerable difference. If one looks with the right eye a little more is seen around the right side of the object and a little less around the left. The right eye image is therefore different from the left eye image. When we look with both eyes we get both images at the same time and this fact gives us an impression of depth, solidity. That this is true is proved by the fact that when we look with the right eye at a picture of objects as seen by the right eye and at the same time with the left eye at a picture of the same objects as seen by the left eye, we believe that we are looking at a single real object and not at a picture at all. This is the principle of the stereoscope, where a right eye picture is made to fall upon the right eye and a left upon the left, and the appearance of depth is thus produced. (2) If one looks at a pencil which touches the end of the nose the eyes converge. If one moves the pencil farther and farther away this convergence becomes less and less. Convergence is a muscular movement and we are as conscious of it as of a movement of the arm. If one reaches across the table for a book one does not say that the extensors contract, etc. One merely says "I reach." If one converges upon an object near at hand one does not say, " I contract the medial recti of my eyes " (Fig. 98), but merely that one looks at something near by.

In this way one " feels " around with his eyes and gains some conception of differences in the distances of

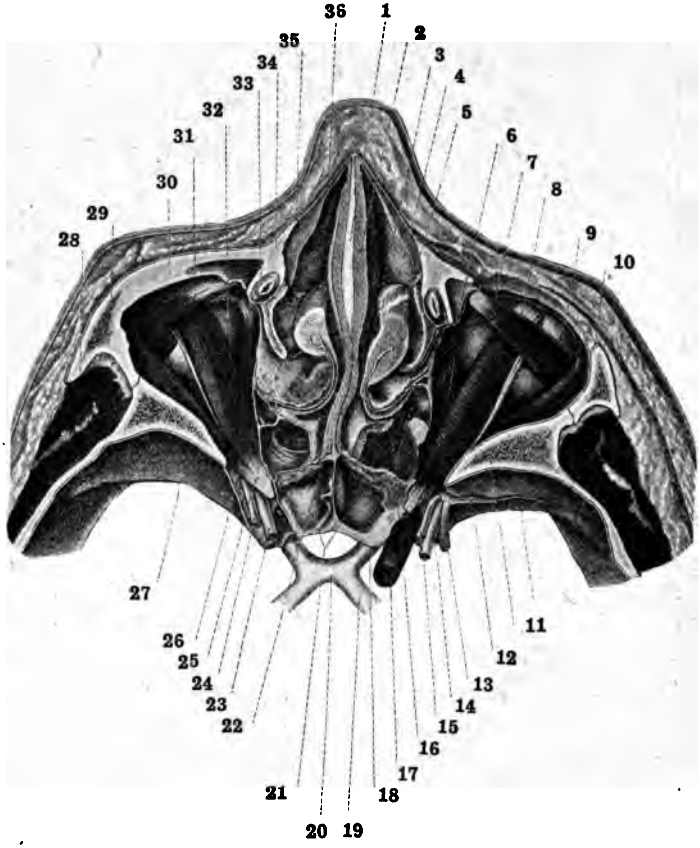

Fig. 98. — Muscles of the eye. 1, cartilage of nasal septum; 2, mucosa of septum; 3, nasal passage; 4, atrium; 5, middle conch (turbinated) bone; 6, median rectus muscle; 7 and 8, inferior rectus and inferior oblique muscles; 9, lateral rectus muscle; 10, outer edge of orbit; 11, sphenoid bone; 12, supra-orbital fissure; 13, ophthalmic nerve; 14, oculo-motor nerve; 15, abducens nerve; 16, ethmoidal sinus; 17, internal carotid; 18, optic nerve; 19, optic tract; 20, optic chiasma; 21, sphenoidal sinus; 22, vomer; 23, oculo-motor nerve; 24, abducens nerve; 25, common tendon of eye muscles; 26, ophthalmic nerve; 27, middle cranial fossa; 28, temporal muscle; 29, zygomatic bone; 30, infra-orbital margin; 31, branch of oculo-motor nerve for the inferior oblique muscle; 32, right eyeball; 33, lachrymal duct; 34, frontal process of maxillary bone; 35, edge of piriform opening; 36, lateral nasal cartilage. (Toldt.)

various objects from the observer. (3) If one looks out of the window at a tree one finds that the cord of the window shade looks double, but if on the other hand, one converges upon the shade cord one finds that it is single whereas the trees now appear doubled. This effect cannot be reproduced in the picture, for here that which is double is always double and hence corresponds to two objects, not one object seen as two. These then are the three signs by which we perceive solidity and get an idea of a world of three dimensions.

The Ear. — The ear (Fig. 99) is divided into three parts, the external, the middle, and the internal. The external ear consists of the projecting part (pinna) and the external acoustic canal (or meatus). The latter is open at one end to the exterior, but the other end is closed by a membrane (the eardrum). The middle ear is a small cavity which is separated by the drum from the external acoustic canal, but is connected with the upper part of the pharynx by the auditory tube of Eustachius. It also communicates with the cells in the mastoid part of the temporal bone. Between the middle ear and the internal ear are two openings, the vestibular window (fenestra vestibuli) and the cochlear window (fenestra cochleæ), each of which is covered by a membrane. Within the cavity of the middle ear is a chain of little bones (ossicles) stretching from the drum to the fenestra vestibuli and so placed and jointed together that every movement of the drum is transmitted, diminished in extent but increased in strength, to the fenestra vestibuli, the membrane covering which is alternately pushed in and drawn out by the adjacent ossicle which adheres to it. The internal ear consists of three parts, the vestibule (the organ giving us a knowledge of the position of the head), the semicircular canals (the organs giving us the knowledge of the motion of the head), and the cochlea (the organ of hearing). The cochlea resembles a snail shell. The spiral canal which would be occupied by the body of the snail is divided into two parts or canals (scalæ, ladders), an upper and a lower, each lined by epithelium and called scala vestibuli and scala tympani respectively. At the apex of the snail shell a gap in the horizontal partition which forms the floor of the scala tympani and the roof of the scala vestibuli permits free communication between the two scalæ. The base of the snail shell is formed by the bony wall of the middle ear in such a way that the vestibular window opens (in so far as it may be said to open since it is covered by a membrane) into the scala vestibuli and the cochlear window " opens " into the scala tympani. Having made ourselves acquainted with the essential anatomic features,

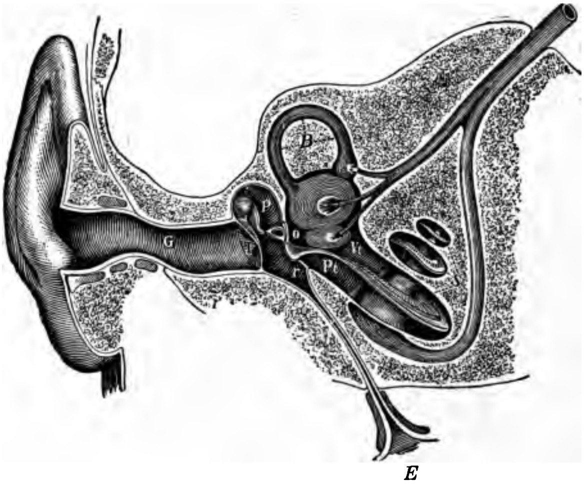

FIG. 99. — Semidiagrammatic section through the right ear. *G*, External, acoustic meatus; *T*, tympanic membrane; *P*, tympanic cavity; *o*, fenestra vestibuli; *Pt*, scala tympani; *r*, fenestra cochleæ; *B*, semicircular canal; *S*, cochlea; *Vt*, scala vestibuli; *E*, auditory (Eustachian) tube. (Czermak.)

let us turn to the question of how these structures mediate the sensation of sound.

The air waves which proceed from a body in vibration, and which constitute sound, travel along the external acoustic canal and strike upon the eardrum. In this way the eardrum is set in motion. The ossicles which form a chain from the drum to the internal ear are so arranged that the first, which through being adherent to the drum follows the motions of the drum, sets the others in motion. This motion which the ossicles receive from the drum they transmit to a membrane which covers the fenestra vestibuli and to which the last of the ossicles is adherent. This membrane therefore follows all the motions of the tympanic membrane. Beyond the fenestra lies a column of liquid (endolymph) in the scala vestibuli, which transmits the motion of the vestibular window-curtain up to the end of the cochlea through the hole in the partition and back by the scala tympani to the cochlear window, which is forced outward toward the middle ear. Thus every time the drum is pushed in toward the cavity of the middle ear, the membrane covering the cochlear window is also pushed out toward the middle ear. Now, the cochlea is lined with a peculiar membrane the action of which is not clearly understood, but it is probable that the motion of the endolymph, as it oscillates back and forth, stimulates mechanically the epithelial cells of this membrane. It is not improbable that vibrations of different rates (*i.e.* notes of different pitch) stimulate different parts of the scala and consequently we are able to differentiate between sounds by attaching to the sensation of a vibration in the ear the local sign of the part of the scala stimulated. Acuity of hearing would then correspond to delicacy of touch and the power to distinguish between difference of pitch would correspond to power of localization. This stimulus which affects the epithelial cells of the cochlea is transmitted by them to the nerve endings which have their cell-bodies in the neighboring ganglion of the cochlear branch of the eighth cranial nerve, and the impulse passes through these cell-bodies and thence by their axones to the brain.

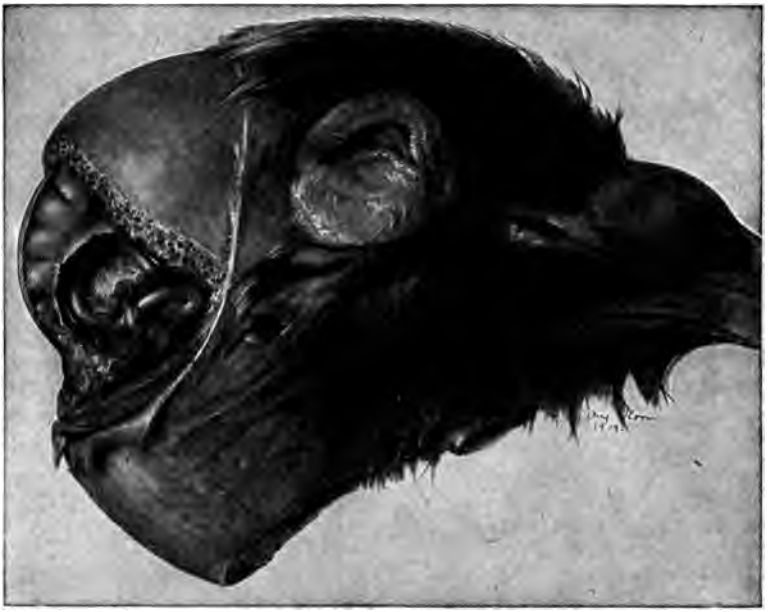

FIG. 100 *A*. — Dissection to show the position of the three semicircular canals in the pigeon. The canal which lies in the vertical antero-posterior plane is to the left, that in the horizontal plane to the right, and that in the vertical transverse plane runs toward the observer and lies near the middle of the dissection. (Howell, from dissection by Dr. Esther Rosencrantz.)

The Semicircular Canals. — Let us turn now to a structure adjacent to the cochlea which is not concerned with hearing but with the sense of equilibrium, namely to the vestibule and the semicircular canals (Figs. 99, 100 *a*, and 100 *b*). These structures are hollow, contain endolymph, and are connected with one another. At certain regions within the semicircular canals long hair-like processes project into the endolymph. In the vestibule there are patches of such hairs and among the hairs lie granules of calcium carbonate (otoliths, ear stones). These hair cells are in communication with the dendrites of a set of neurones whose cell-bodies are situated near by and whose axones form the vestibular branch of the eighth cranial (acoustic) nerve, along which impulses are transmitted toward the cerebellum. It is to be borne in mind that it is to the cerebellum that the muscle sense fibers also pass. The function of these structures has been determined with a high degree of probability. They are organs of equilibrium and of position and act in conjunction with the fibers of muscle sense to give us a knowledge of the position of the head in space. When the head is quiet this position is indicated by the pressure of the otoliths which is exercised in one direction or in another depending on the position of the head. If the head begins to move, the pressure relation of the otoliths is changed and in addition to this the endolymph in the semicircular canals moves also, stimulating in so doing the hair cells in the canals. The arrangement of the

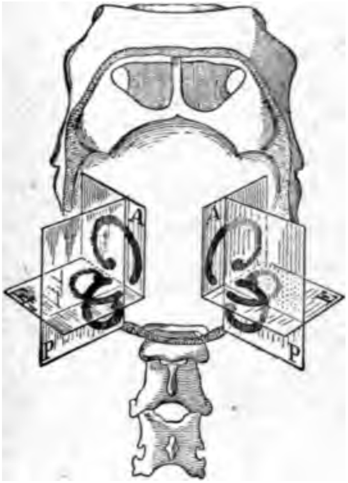

FIG. 100 *B*. — Diagram to show the position of the semicircular canals in the head of the bird. On each side it will be seen that the three canals lie in planes which are at right angles to one another. The external or horizontal canals (*E*) of the two sides lie in the same plane. The anterior canal of one side (*A*) lies in a plane parallel to that of the posterior canal (*P*) of the other side. (Ewald.)

canals in three different planes would naturally contribute to the efficiency of the organ, and to the varying degrees by which each canal is affected would correspond the varying direction of the motion, so that the former is taken by us as an indication of the latter.

CHAPTER VII

THE CIRCULATION

Introduction. — We have seen that in man as in all the more complicated multicellular organisms, the neurone and the muscle fiber present great specialization along certain lines. The amœba showed the properties of irritability, contractility and conductivity, but in the cells above mentioned these properties were developed to an extraordinary degree and this at the expense of the other vital properties. But what have we in the amœba which corresponds to the blood and the circulatory system?

Every cell in the organism takes in nourishment and must throw out the waste products of its own activity. Take the muscle fiber for example. The raw materials from which its protoplasm is renewed and its energy derived must come from without, while those products which cause fatigue and so forth must be got rid of. Hence, if these cells are not in direct contact with the outer world, there must be some means of communication between the two. Just as the organism as a whole profits by the great nerve muscle mechanism which we call the voluntary musculature, so the whole organism is put into communication with the outside world by means of a complicated system of muscular tubes, the blood vessels, through which a fluid is kept moving by means of a muscular pump, the heart, all this musculature being controlled by its nerves.

The uses of this blood-stream are then (1) to supply nutriment, including oxygen, to the tissues, (2) to remove waste products, including carbon dioxide, and (3) in the case of warm-blooded animals to equalize the temperature in all parts of the body.

The Circulation as a Whole. — A few general statements will assist the student in understanding the circulatory mechanism. The heart is made up of four distinct chambers, the two atria[1] ("auricles") and the two ventricles. Of these the atria receive blood from the veins and by their contraction drive it into the ventricles. The latter contracting in their turn pump the blood out of the heart and through the veins to the rest of the body. The arrangement of these chambers, of their valves and of the blood vessels, is such that the blood passes from the systemic veins to the right atrium, thence in order to the right ventricle, the pulmonary artery, the capillaries of the lungs, the pulmonary vein, the left atrium, the left ventricle, the systemic arteries, the

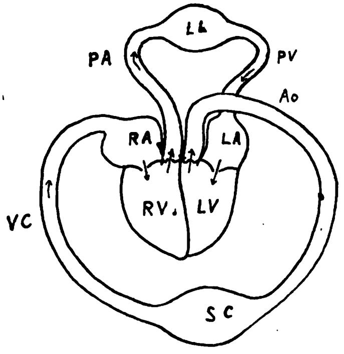

Fig. 101. — Schematic representation of the circulation. *VC*, vena cava; *RA*, right atrium; *RV*, right ventricle; *PA*, pulmonary artery; *LL*, pulmonary capillaries; *PV*, pulmonary veins; *LA*, left atrium; *LV*, left ventricle; *Ao*, aorta; *SC*, systemic capillaries. At the beginning of *PA* and of *Ao* are the semilunar valves; between *RA* and *RV* is the tricuspid valve and between *LA* and *LV* is the bicuspid (mitral) valve.

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[1] It is usual, but by no means universal, to call the upper chambers of the heart the "auricles" and to designate as "auricular appendices" the "ear-like" pouches which open one into each of the "auricular" cavities. The more recent and progressive anatomies, however, are adopting the designation "atrium" for the upper chamber and that of "auricle" for the ear-like pouch already referred to.

systemic capillaries, the systemic veins, to the right atrium again. (See Fig. 101.)

The function of the circulation is the interchange of gases and of substances in solution between the tissues and the blood, on the one hand, and the blood and the exterior of the body on the other, and it is plain that the most suitable conditions for such activity are found when the blood-stream moves very slowly through very thin-walled vessels. These conditions are fulfilled in the capillaries. Every part of the body is supplied with its system of minute vessels (capillaries) where the blood lingers to part with its nutritive substances and to take up waste products of tissue activity. Besides these areas which are nutritive in character there are the capillary areas concerned with elimination of waste products from the body, *e.g.*, the capillaries of the kidney, the lungs and the skin, and for the taking up of substances which lie outside of the body, *e.g.*, the capillaries of the lungs and intestines. These matters will, however, be treated more in detail under the heading of metabolism. (The more important arteries and veins and their distribution to various parts of the body are shown in the accompanying figure, Fig. 102. The heart itself is shown in Fig. 103.)

The Heart as a Pump. — The atria and ventricles are composed of muscles so disposed that when the muscle bands contract they diminish the capacities of the chambers which they inclose. Such an event must expel the blood from the contracting chamber in the direction of the arrows, since its passage in the opposite direction is prevented by the valves (Fig. 101). The sequence of events in a normal heartbeat is as follows: A wave of contraction starts at the mouths of the great systemic veins and spreads with great rapidity over the musculature

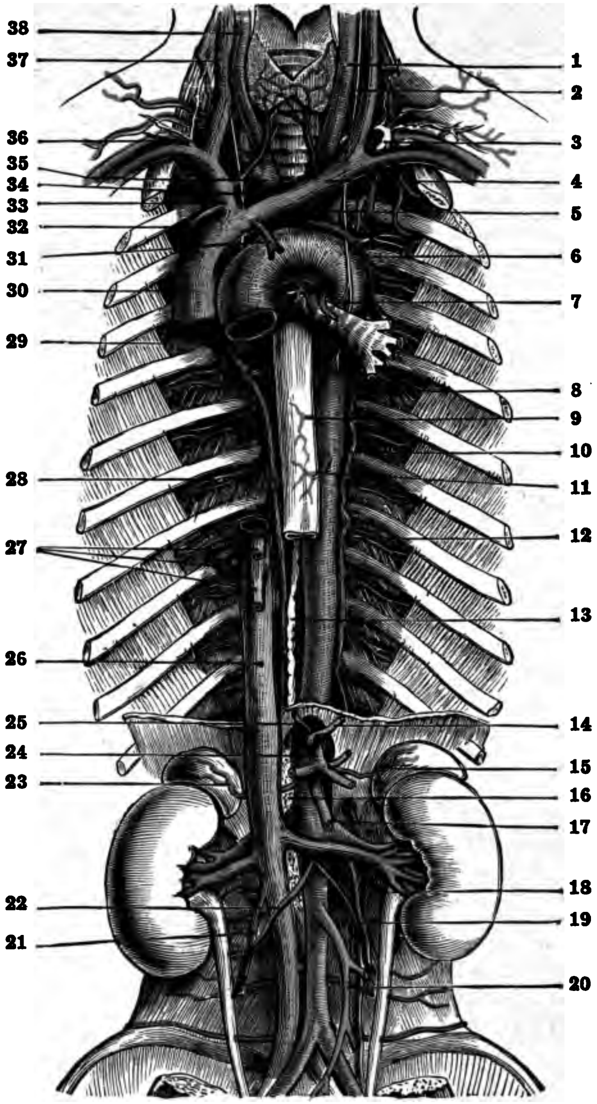

FIG. 102. — Thoracic and abdominal aorta. 1, left common carotid artery; 2, left vagus nerve; 3, thoracic duct; 4, left innominate vein; 5, left subclavian artery; 6, left superior intercostal vein; 7, recurrent (laryngeal) nerve; 8, accessory hemiazygos vein; 9, œsophagus; 10, left upper azygos vein; 11, œsophageal branches from aorta; 12, hemiazygos vein; 13, thoracic duct; 14, left phrenic artery; 15, left middle suprarenal artery; 16, receptaculum chyli; 17, superior mesenteric artery; 18, left ascending lumbar vein; 19, left spermatic vessels; 20, inferior mesenteric artery; 21, right spermatic vein; 22, right spermatic artery; 23, right middle suprarenal artery; 24, cœliac artery; 25, right phrenic artery; 26, inferior vena cava; 27, hepatic veins; 28, hemiazygos vein; 29, azygos vein; 30, superior vena cava; 31, trunk of pericardial and thymic veins; 32, internal mammary vein; 33, right innominate vein; 34, right vagus nerve; 35, innominate artery; 36, right lymphatic duct; 37, right internal jugular vein; 38, right common carotid artery. (Morris.)

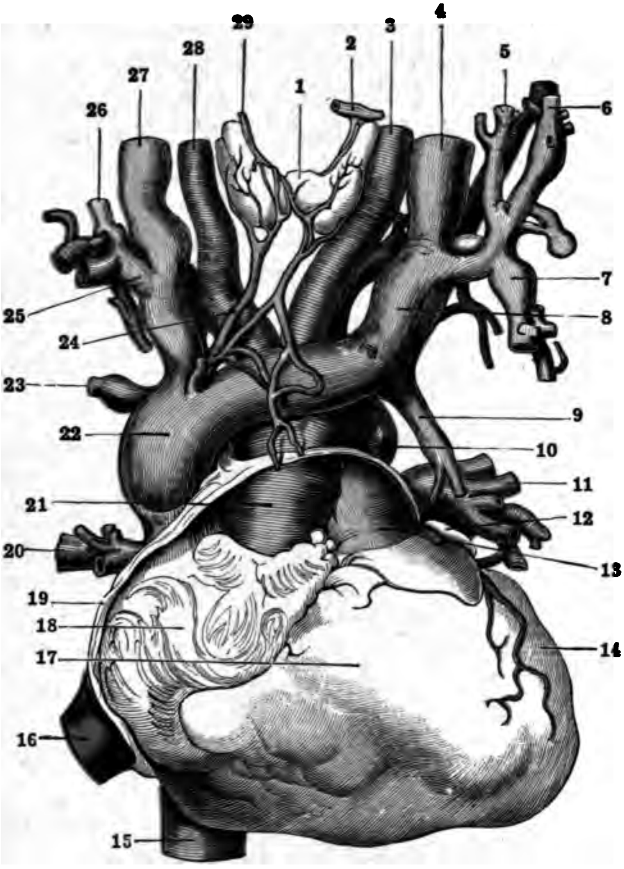

Fig. 103. — Anterior view of the heart with large arteries and veins. 1, thyroid body; 2, left superior thyroid vein; 3, left common carotid artery; 4, internal jugular vein; 5, left vertebral vein; 6, external jugular vein; 7, left subclavian vein; 8, left innominate vein; 9, left superior intercostal; 10, ligamentum arteriosum; 11, left pulmonary artery and vein; 12, left auricle; 13, pulmonary artery; 14, left ventricle; 15, aorta; 16, inferior vena cava; 17, right ventricle; 18, right atrium; 19, pericardium; 20, right pulmonary artery; 21, aorta; 22, superior vena cava; 23, azygos vein; 24, inferior thyroid vein; 25, subclavian vein; 26, vertebral vein; 27, internal jugular vein; 28, right common carotid artery; 29, right superior thyroid vein. (Morris.)

of both atria. These contract simultaneously, driving blood into the ventricles. The wave of contraction has meanwhile passed from atria to ventricles and now spreads over the ventricles, which contract simultaneously.

The Wave of Contraction.—We know that if a stimulus be applied to one end of a muscle, a wave of contraction sweeps on over the entire tissue. It is therefore easy to conceive how a muscle contraction can sweep over the musculature of the atria which is practically continuous. But the musculature of the ventricles is largely independent of that of the atria. There is in fact only one important available connection between the atria and the ventricles, namely, the so-called atrioventricular bundle (Fig. 104). This begins in the partition wall of the two atria (inter-atrial septum) and after passing over into the ventricles as a compact bundle divides and is spread out over the inner surface of both ventricles. As in the case of skeletal muscle the contraction of the heart muscle gives rise to electrical phenomena and through these

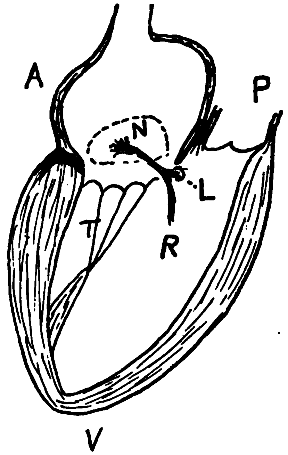

FIG. 104.—Diagram showing position of atrioventricular bundle. The muscular walls of the right atrium and right ventricle have been in considerable measure cut away so that the observer looks toward the inter-atrial and inter-ventricular septa. *A*, atrium; *V*, ventricle; *T*, tendinous bands (chordæ tendineæ) running from one of the leaves of the tricuspid valve (which is drawn down into the ventricle) to a prolongation of the ventricular musculature (papillary muscle). *P*, pulmonary artery showing one of the three-cornered valves pushed up into the artery. In the region inclosed within the dotted lines, the surface of the inter-atrial septum has been dissected away, disclosing *N*, the upper end or node of the atrioventricular bundle. From here the bundle runs along the upper edge of the inter-ventricular septum until it divides into two branches, one (*R*) passing to the right ventricle, the other (*L*) to the left ventricle. This "*A–V* bundle" is the most important physiologic connection between the atria and ventricles.

phenomena the action of the heart may be studied clinically. The photographic record of these electric changes is known as an electrocardiogram.

The Apex Impulse. — When the heart contracts, a tap or thump may be felt when the hand is placed upon the chest wall. This is the "apex beat." Instruments used for obtaining graphic records of the apex beat are known as cardiographs. The impact of the heart against the chest-wall is probably due to the fact that when the ventricles discharge the blood forcibly into the curved aortic and pulmonary arteries these vessels become somewhat straightened out and hence thrust the now hardened apex like a drumstick against the chest wall. When the heart contracts it changes in volume, the diminution in size being equal to the amount of blood which is discharged. The amount of blood which is discharged per minute varies, depending upon the output per beat and the number of beats per minute.

Heart Sounds. — If the ear be placed against the chest wall two sounds are heard with each contraction of the heart. They are usually represented by the syllables "lubb-dup." The second of these is undoubtedly due to the snapping shut of the semilunar valves when on completing their systole the ventricles begin to relax. The first sound is due to the closing of the atrioventricular valves and to some sort of vibration of the contracting muscular mass, the exact nature of which is doubtful. The first sound marks the beginning of systole, the second that of diastole.

Pericardium. — Where tendons glide over stationary surfaces and bones form movable joints, friction is greatly reduced by the presence of a bursa or synovial sac. Here the opposite surfaces being smooth and lubricated by synovial fluid the friction is reduced to a minimum. A similar arrangement is exemplified in the pericardium. The relation of the pericardium to the heart is seen in Fig. 105. The visceral layer of the pericardium forms the outer covering of the heart and of the bases of the large blood vessels entering or leaving the heart. The parietal layer is closely applied to the visceral layer, the opposite surfaces being lubricated by a small quantity of liquid (pericardial fluid).

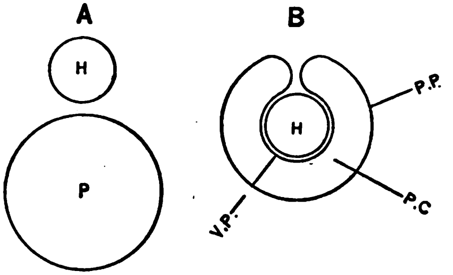

Fig. 105. — Diagram of heart and pericardium. In *A* heart and pericardium are lying separately; in *B* the pericardium is lying around the heart. *H*, heart; *P*, pericardium; *P.C*, pericardial cavity; *P.P*, parietal portion of pericardium; *V.P*, visceral portion of pericardium.

Cause of the Heartbeat. — Whether the rhythmic contractions of the heart are due to the nerve tissue which it contains or is a property of the muscle tissue itself is an unsettled question, but whatever the mechanism is, it has been shown that the stimulus which calls it into action is a chemical one, or, at any rate, is entirely dependent upon the presence of certain salts in the blood. If the blood vessels of the heart muscle (coronary circulation) be perfused with blood, the heart may be removed from the body and it will still continue to beat. With such an "isolated" heart the composition of the circulating fluid may be altered at will and the effect upon its rhythmic contractions observed or graphically recorded. In this way it has been shown that all the constituents of the blood can be dispensed with save these; water containing small quantities of sodium chloride (0.9%), calcium chloride (0.024%), and potassium chloride

0.042%. A solution of this composition is known as Ringer's solution. Even strips of heart muscle will beat when immersed in such a solution. To obtain the best results, however, the most vigorous and long-continued contractions, it has been found advisable to add to the solution dextrose 0.1% and sodium bicarbonate 0.01 — 0.03% and to drive the mixture through the coronary circulation by the pressure from an oxygen tank so that the liquid becomes charged with oxygen.

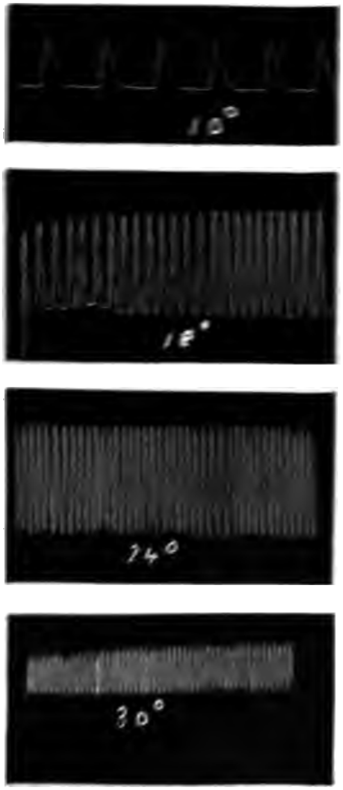

Fig. 106. — Tracing showing the effect upon the force and rate of the heartbeat of altering the temperature of the circulating liquid. (Howell.)

Heat. — As the heartbeat itself is attributable to the character of the circulating medium, so variation in this medium often results in variation in the character of the heartbeat.

Of importance among the changes in question is a change in the temperature of the circulating medium. It has been shown that the highest temperature at which the mammalian heart will beat is 45° C. and that it ceases to beat at 17° C. Between these limits the heart rate increases with increase in temperature and decreases with decrease in temperature (Fig. 106).

Refractory Period. — But if such a solution will keep any part of the heart beating, how is it that under normal circumstances the blood acting at all parts of the heart at once does not keep it all in a state of continuous contraction? In other words how is relaxation possible? In reply this may be stated that the heart, as soon as it has once contracted loses for a time its irritability to every sort of stimulus and therefore relaxes. After a time its irritability gradually returning it attains a condition at which it is again able to respond to a stimulus and then it contracts again. This contraction is in turn followed by another refractory period. It is on this account that a continuous stimulus causes, in the case of heart muscle, a rhythmic response.

Automaticity. — All parts of the heart do not beat at the same rate, some beat faster than others. The most rapidly contracting part of the heart lies in the right atrium. It is here that the first response to the chemical stimulus of the blood occurs, and from here the contraction wave spreads by the atrioventricular bundle to the ventricle. Ordinarily, the ventricle beats at the rate set by the right atrium, but if for some reason this atrium cease to beat, the ventricles themselves will begin to show the effect of the salts in the blood and will beat independently, but at a much slower rate than that ordinarily seen. Thus the rhythmic action of the heart is due to the refractory period and the orderly sequence of the contraction depends upon the fact that the automaticity of the right atrium is greater than that of the ventricles.

Tonus. — It has been stated already (pages 38 and 48), that heart muscle exhibits the phenomenon of tonus. This tonus is both central and peripheral in character, and upon the presence of tonus depends the size of the ventricular cavity. If the tonus decreases, the heart is more dilated at the end of diastole than would otherwise be the case (Fig. 107).

Nervous Control of the Heart. — Although the heart is automatic and contracts rhythmically even when removed from the body, it is, under normal conditions, controlled by two sets of nerve fibers, the cardio-accelerator fibers coming to it by way of the sympathetic and the cardio-inhibitory fibers coming to it by way of the vagus nerve. The cardio-inhibitory fibers have their cell-bodies situated in the medulla where they form a cardio-inhibitory center. This center is in tonic activity, that is, it sends out impulses continually which slow the heart. If the center be stimulated to increased activity, the heart is slowed still further. If this center is inhibited, its inhibitory action upon the heart is lessened and the heart rate is quickened. The location of the cell-bodies of the cardio-accelerator fibers has not been determined. Like the inhibitory fibers, the accelerator are in tonic activity, that is, they are always transmitting impulses which tend to quicken the heart. It has been shown by experiment that on section of these fibers the heart slows down, whereas if they are stimulated the heartbeat is quickened.

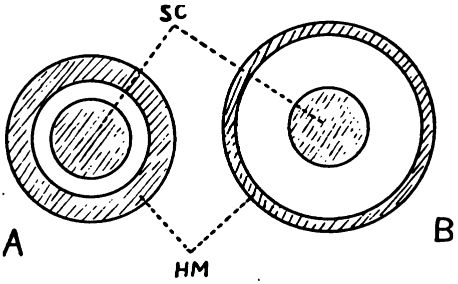

FIG. 107. — Diagram showing effect on output of variations in the tonus of the cardiac muscle. *HM*, musculature of the heart wall; *SC*, cavity of the heart at the end of systole, *i.e.* corresponding in size to the amount of residual blood. The white circle represents the cardiac output. *A*, muscle shows strong tonus; *B*, muscle relaxed. If the residual amount of blood is constant (it is so represented in the figure), the heart which is the more relaxed during diastole puts out more blood per beat.

The cardio-inhibitory center in the medulla and the cardio-accelerator center, wherever it may be, may be stimulated reflexly or inhibited reflexly. Consequently, any observed change in the heart rate may be due to one or both of two causes. (1) Quickened heart rate may be due to excitation of the cardio-accelerator center or to inhibition of the cardio-inhibitory center or to both causes; (2) a slowing of the rate may be due to excitation of the cardio-inhibitory center or to the inhibition of the cardio-accelerator center or to both causes.

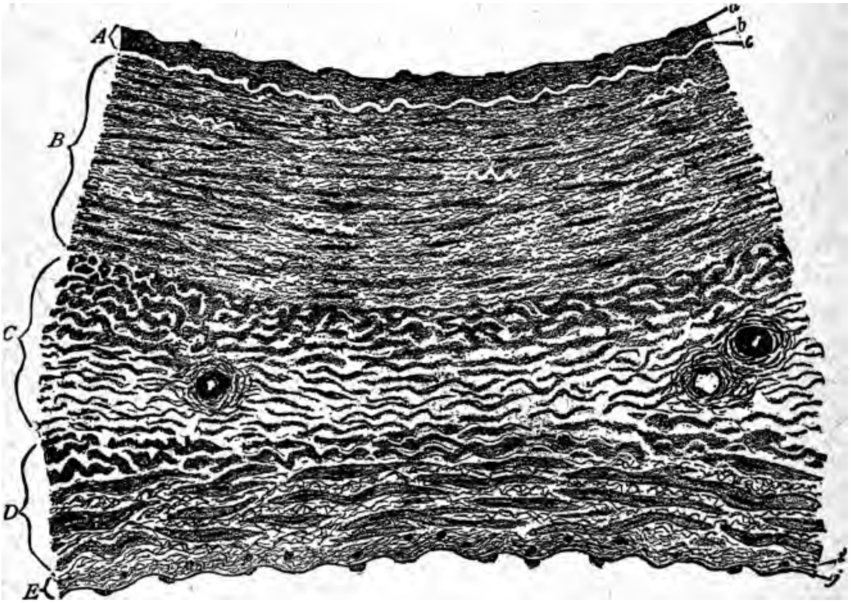

FIG. 108. — From cross section through walls of medium-sized artery and its accompanying vein. *A*, inner coat of artery, consisting of, *a*, endothelial layer, *b*, sub-endothelial layer, and, *c*, elastic layer; *B*, middle layer of artery, consisting largely of plain muscle fibers; *C*, external layer of connective tissue which in this specimen passes over into the external coat of the vein. In this layer are seen the cross sections of vasa vasorum. *D*, middle layer of vein; *E*, inner layer of vein consisting of sub-endothelium, *i*, and endothelium, *j*. (Bailey.)

In the case of the cardiac acceleration which occurs during exercise, it has been shown that the principal factor is the inhibition of the tonus of the vagus, although to a certain extent the stimulation of the accelerators also plays a part. Besides their effect on the heart rate, the nerves affect in opposite ways the strength of the beat. The vagus decreases its force while the sympathetic fibers increase it.

Extensibility and Elasticity. — Passing now from the pump, the heart, to the tubes, the arteries, into which the blood is pumped, we find that their most important characteristic is that they are both extensible and elastic. We should always bear in mind the differences between the terms extensible and elastic. Molasses candy is extensible but not elastic, ivory is very elastic but only to a small extent extensible or what amounts to the same thing, compressible. Rubber is both extensible and elastic. By being extensible we mean that the object can be stretched, by elastic, that it returns to its former shape as soon as the stretching force ceases to act. Consequently, when the heart contracting drives blood into the arteries they are distended, but when the cardiac systole is over they return again to the original size, squeezing along the blood, as they do so, into the capillary areas. Yellow elastic and muscular tissues occur most abundantly in the arteries, which are therefore most distensible and contractile; the white fibrous connective tissue predominates in the veins, which are therefore in-

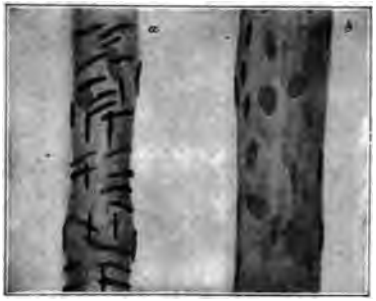

FIG. 109. — Precapillary vessels from mesentery of cat: *a*, precapillary artery; *b*, precapillary vein possessing no muscular tissue. (Bailey.)

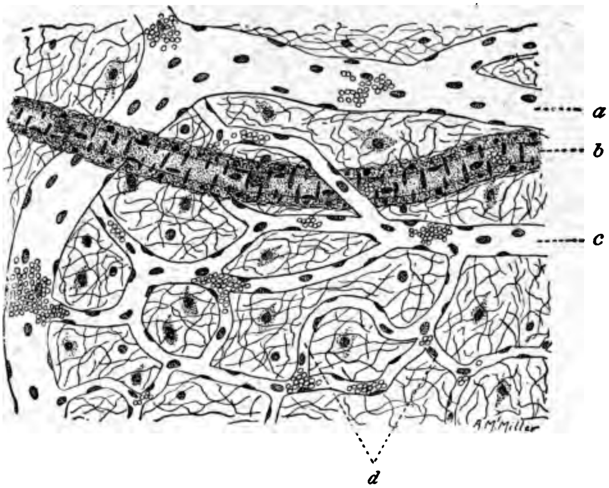

FIG. 110. — Capillary network from the human pia mater. *a*, vein; *b*, arteriole; *c*, large capillary; *d*, small capillaries. (Bailey.)

extensible; the capillaries are incapable of distention, and when without muscle fibers are without contractility (Figs. 108, 109, 110).

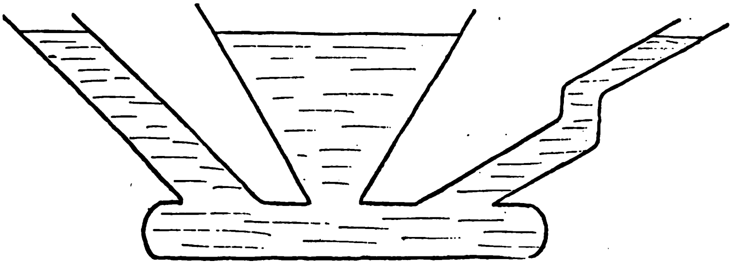

FIG. 111 *A*. — Diagrams illustrating the principle of the manometer. Several connecting tubes containing a liquid. Note: the level of the liquid is the same in all the tubes.

Manometers and Blood Pressure. — If we pour water or other liquid into a series of tubes of irregular shape all of which are connected together, we shall find that the liquid rises to the same level in all of them (Fig. 111 *a*).

Of course if we use a U-shaped tube the same thing holds true, the level is the same in both limbs of the tube. This is because the downward pressure upon the liquid (that of the atmosphere) is the same on the two sides (Fig. 111 *B*). Suppose that instead of using the same liquid in both limbs of the U, we use water in one limb and mercury in the other. These liquids will dispose themselves so that the pressure of the column of water is equal to the pressure of the column of mercury. If we measure the column of mercury and find that it amounts to one cm., then we shall find that the corresponding column of water is thirteen cm. high, for mercury is thirteen times as heavy as an equal quantity of water (Fig. 111 *C*). If instead of a column of water we have a rubber bulb full of liquid or air and we squeeze this bulb, we find that we can drive up the mercury to a certain height. If we exert a less pressure, then the column will not rise so high; if the pressure be greater, the column will rise higher. Thus we can use the height of the mercury as a gauge or measure of the amount of pressure produced by the bulb (Fig. 111 *D*). If we use water instead of mercury, the result would be the same excepting that in every case the column of water would be thirteen times as high as the corresponding column of mercury. Such pressure gauges are known as manometers. For recording all except very small pressures the mercury

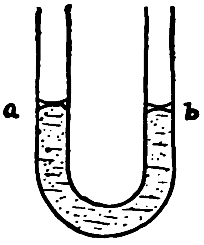

FIG. 111*B*. — U-tube with the liquid standing at the same level in both limbs.

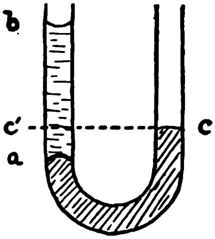

FIG. 111 *C*. — U-tube contains two liquids which cannot be mixed and are of different densities. If the liquids be mercury and water, then *ab* will be thirteen times *ac'*, for mercury is thirteen times as heavy as water.

manometer is to be preferred. For instance, the pressure of the atmosphere is equal to a column of mercury 760 mm. high, or to a column of water thirteen times 760 mm. or 9880 mm. high, so that in this case as in many others, it is considerably more convenient to employ the mercury than the water manometer.

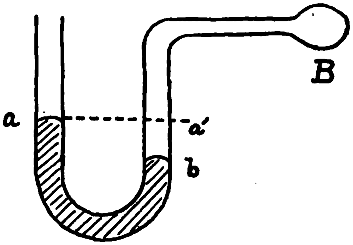

FIG. 111 *D*. — Here one limb of the U is connected with a bulb (*B*). If *B* be squeezed, the liquid will fall in the limb connected with *B* and rise in the other limb. The difference in height of the two columns of liquid (*b*, *a*) measures the amount of pressure with which *B* is squeezed.

If we attach a rubber bulb containing 50 cc. of water to the end of a long glass tube also containing water and if we squeeze the bulb empty, an equal amount of water, 50 cc., must pass out from the other end of the glass tube at the same time.

If we connect a manometer with this glass tube by means of a side tube, we find that during the compression of the bulb, the mercury in the manometer rises to a considerable height, but that during the pause between the acts of compression, it quickly falls again to zero. If the outlet at the end of the glass tube be decreased in size, then on compression of the bulb, the mercury will rise higher because the pressure required to force the water through the narrower opening is greater. If on the other hand the size of the opening be increased, the pressure required will not be so great and, consequently, the manometer will not register as high as before. In short, the greater the resistance to the outflow the greater the amount of force required to empty the bulb.

Suppose that instead of a rigid glass tube we employ a rubber tube which is both extensible and elastic. This system is much more like the circulation, for the bulb represents the heart, the rubber tube represents the extensible-elastic arteries, while the opening which varies in size corresponds to the small arteries which vary in caliber from time to time (Fig. 112). If this heart (*B*) pumps blood into arteries (*A*) and we close the outlet (*p*), then, *A* will swell up and the pressure will rise until it is equal to the highest pressure in the heart and the heart will be unable to pump in any more. If the heart ceases to beat and we open the outlet (*p*), then the artery being elastic will contract and drive the blood out (at *p*), with a rapidity which will depend both on the previous distention of the arteries (*i.e.* on the pressure exerted by the wall of *A*) and the size of the outlet.

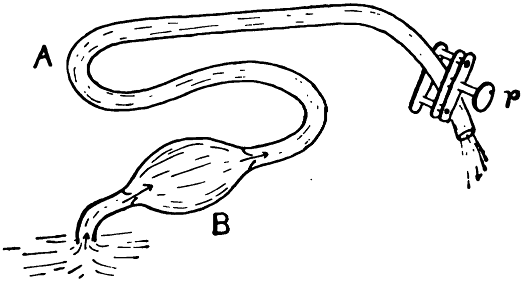

FIG. 112. — Diagram of model of the heart and vessels. *B*, syringe bulb, representing the heart; *A*, rubber tube, representing the arteries; *p*, a screw cock representing the variable "peripheral" resistance in the region of the arterioles and small arteries.

In the circulation these two processes occur intermittently, with an alternating predominance first of one and then of the other. Each beat of the heart pumps blood into the arteries (*A*); the caliber of the peripheral vessels (*p*) is too small to let a whole heart-full of blood pass out immediately, and so the arteries become distended. As soon as the heart pause occurs, the arteries begin to contract. But before the distention has disappeared, there comes another beat and the arteries are again distended. Thus the pressure in the arteries rises and falls but never reaches zero. The highest point to which the pressure of the blood in the arteries is raised at each heartbeat is known as the systolic pressure. The diastolic pressure is the amount of pressure left after there has been squeezed out from the arteries into the capillaries the amount of blood which is expelled from the heart in a single cardiac cycle (Fig. 113).

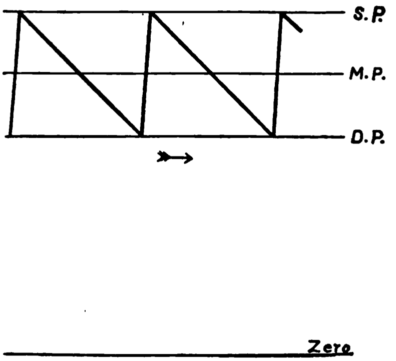

FIG. 113. — Pressure changes in the arteries. The curve representing these changes is the heavy black line which rises suddenly to the line *S.P* (systolic pressure) and then falls more slowly to the line *D.P* (diastolic pressure): *M.P.*, mean or average pressure.

From what has just been stated it follows that there are in the circulation certain physical factors each of which may vary and in doing so may cause variations in the blood pressure and the velocity of the blood flow. These factors are:

(1) The rate and strength of the heartbeat.

(2) The resistance (known as " peripheral resistance ") which is offered to the flow of blood through the small arteries (arterioles).

Determination of Blood Pressure in Man. — The method of determining the blood pressure in animals is easily understood, for it is only necessary to open a blood vessel in an anesthetized animal, connect it with a manometer, and read off the number of millimeters indicated by the instrument. This is known as direct manometry. Obviously direct manometry is not applicable in the case of human beings, and indirect methods must be resorted to. The methods employed in the case of man are numerous, but all have this in common, that the meaning and accuracy of the readings of the instrument must in every case be established by experimentation on animals which must involve a comparison of the method in question with the direct method. It has been found, for instance, that if we place a stethoscope upon the brachial artery and then compress the artery above the point at which the stethoscope is applied, we shall find variation in the sound of the pulse depending upon the amount of pressure we exert. Thus when the pressure exerted upon the arm is high no sound is heard at all, but as the pressure falls one begins to hear a click which corresponds to each heartbeat, as the pressure falls still further the pulse becomes louder and then suddenly faint again. The meanings of the change in sound have been determined through experiments upon anesthetized animals by comparing the former with the pressure changes in a manometer inserted directly into the vessels and in this way it has been shown that at the appearance of the sound the pressure exerted upon the vessel is equal to the systolic pressure and when the loud sound suddenly becomes weak the pressure upon the artery is equal to the diastolic pressure. The amount of pressure upon the arm can readily be measured and from this the systolic and diastolic pressures within the artery can be inferred.

Nervous Control of the Arteries. — Just as the heart is automatic and has its power of contraction independent of the central nervous system, so is the tonus of the blood vessel an inherent property and independent of the central nervous system. But as the heartbeat is modified by nerves coming from without, so the tonus of the blood vessels (and with it their caliber) is modified by nerves. The vasomotor nerves are of two kinds — excitatory and inhibitory, and since an excitation of the muscles of the blood vessels leads to constriction of the caliber of the vessels, while an inhibition leads to a dilatation of the vessels, these nerves are often spoken of as the vasoconstrictors and vasodilators, respectively.

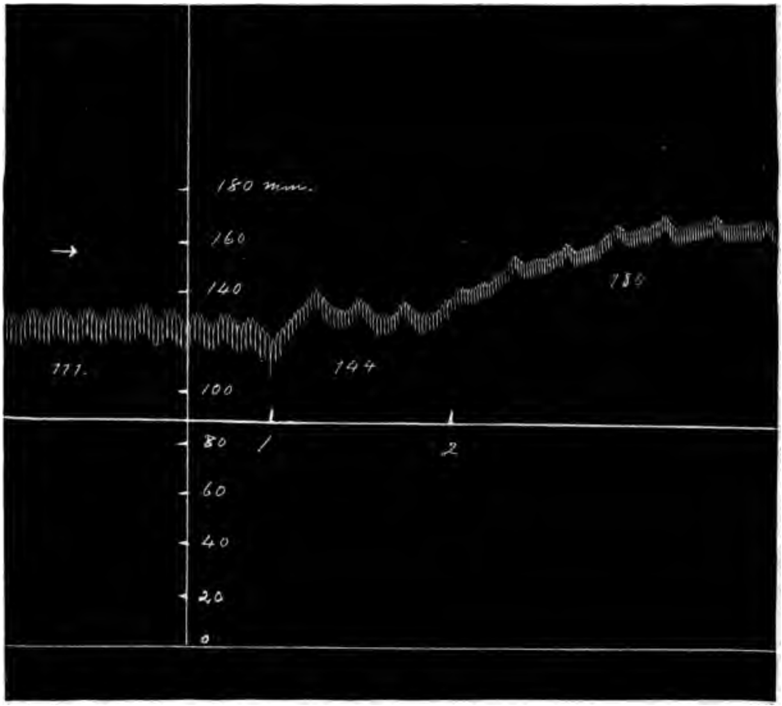

FIG. 114. — Tracing to show the effect of section of the two vagi in the dog upon the rate of the heartbeat and upon the blood pressure. 1 marks the section of the right vagus; 2, section of the left vagus. The numerals on the vertical mark the blood pressures; the numerals below the blood pressure tracing give the heart rate per minute. This tracing should be read from left to right and is made by connecting the artery of the animal with a mercury manometer, the rise and fall of which is recorded upon a moving surface. (Howell.)

During functional activity the organs are flushed with blood and it is evident that dilatation of the arterioles has taken place. It is not possible, however, to decide *a priori* whether such a dilatation is to be attributed to an inhibition of the constrictors or to an excitation of the dilators or to both. Careful investigation must be made in each case to decide this point.

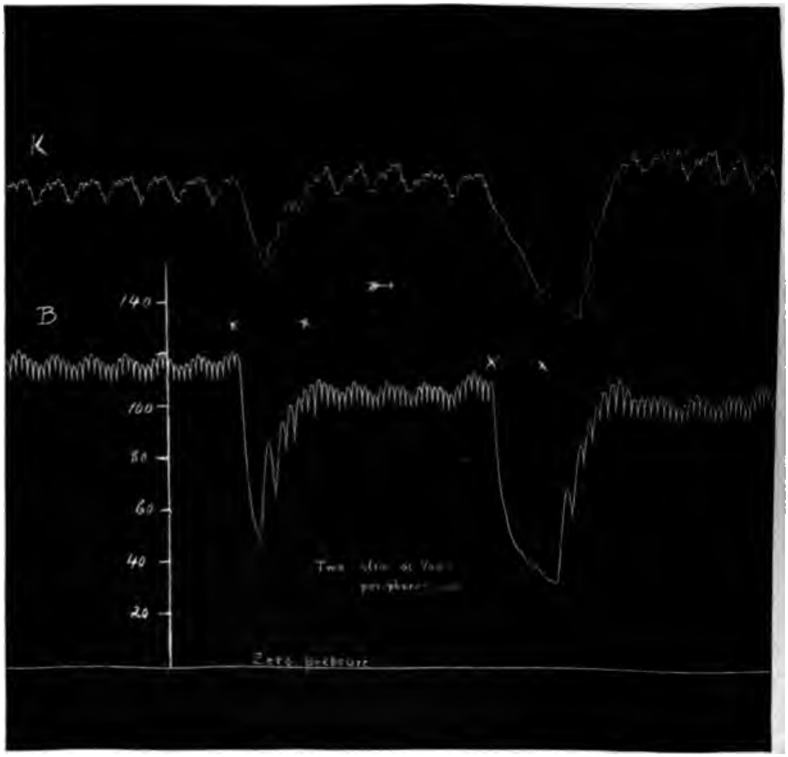

Fig. 115. — Tracing showing the inhibition of the heart through the stimulation of the vagus in the dog. Record *B* is the blood pressure tracing. The vagus was stimulated twice. The marks ×, ×, indicate the beginning and end of the stimulus. The first stimulation was weak and it will be seen that the heart "escaped," began beating again before the stimulus was withdrawn. The second stimulus was stronger and the inhibition lasted for some time after the removal of the stimulus. The upper curve, *K*, indicates changes in the volume of the kidney. It will be noted that when the heart stops and the blood pressure falls the kidney, like the other organs, diminishes in volume. (Howell.)

The constrictor center lies in the medulla near the cardio-inhibitory center. From it the vaso-constrictor fibers pass by way of the sympathetic system to practically all the blood vessels of the body. The vaso-dilator center has not been located, but vaso-dilator fibers have been demonstrated passing in considerable numbers to the salivary glands, vessels of the mouth, and to the erectile tissue of the penis (cf. p. 256), but only sparingly to other tissues and organs of the body. It may not be amiss to reiterate here what has already been said regarding the advisability of bearing in mind the function, origin, and destination of every nerve fiber or group of nerve fibers which occupies the attention. In the case of the cardiac and vascular nerves we should carefully distinguish the following:

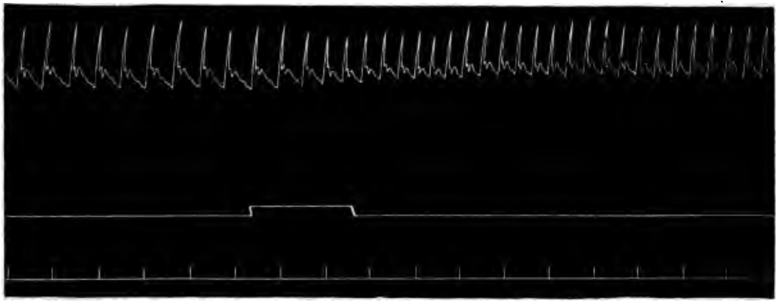

FIG. 116. — Tracing to show the acceleration of the heart rate in the dog upon stimulation of the accelerator (cardio-excitatory) fibers. The uppermost line gives the heart rate as recorded by a spring manometer inserted into the carotid artery; the break in the middle line indicates the duration of stimulation; the bottom line marks seconds. The pulse rate was increased from 105 to 135 per minute. The heart did not recover its normal rate until thirty seconds after the stimulation. (Howell.)

For the heart,

1. Efferent inhibitory nerves from the medulla to the heart (Fig. 114, 115).
2. Efferent excitatory nerves from the brain to the heart (Fig. 116).

3. Afferent inhibitory nerves from various peripheral regions to the cardio-excitatory center.
4. Afferent excitatory nerves from various peripheral regions to the cardio-excitatory center.
5. Afferent excitatory nerves from various peripheral regions, *e.g.* the lungs, to the cardio-inhibitory center.
6. Afferent inhibitory nerves from various peripheral regions, *e.g.* voluntary muscles, to the cardio-inhibitory center.

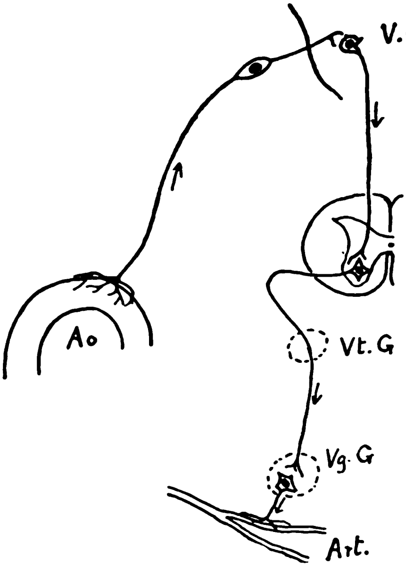

FIG. 117. — Scheme of a vaso-constrictor reflex. *Ao*, aorta; *V.C.C. in M*, vaso-constrictor center in medulla; *Vt. G*, vertebral ganglion; *Vg.G*, vagrant ganglion; *Art*, arterioles of the abdominal viscera. Dilatation of the aorta due to increased internal pressure is a mechanical stimulus to the afferent fibers, which at once transmit an impulse. This impulse inhibits the center so that the arterioles fail to receive impulses by way of vaso-constrictor nerves. The arterioles therefore lose their central tonus and dilate. Consequently the blood pressure falls and the dilatation of *Ao* is relieved.

And for the arteries,

1. Efferent inhibitory nerves from the vaso-dilator center to the musculature of the arteries.
2. Efferent excitatory nerves from the vaso-constrictor center to the musculature of the arteries.
3. Afferent inhibitory nerves from various peripheral

regions (*e.g.* the aorta) to the vaso-constrictor center.

4. Afferent excitatory nerves from various peripheral regions (*e.g.* the skin) to the vaso-constrictor center (Fig. 117).
5. Afferent excitatory nerves from various peripheral regions to the vaso-dilator center.

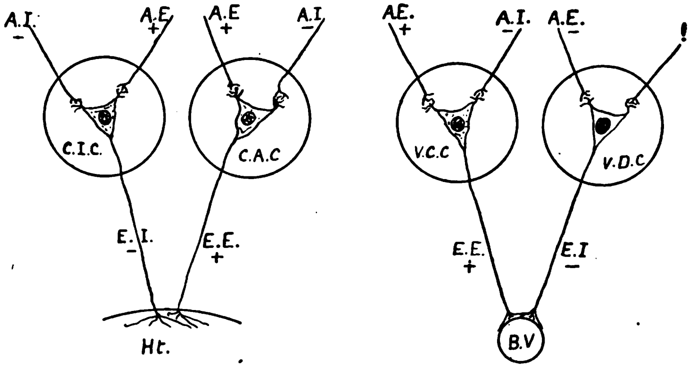

FIG. 118. — Diagram: nervous control of the heart and arteries. *A.I*, afferent inhibitory fibers; *A.E*, afferent excitatory fibers; *C.I.C*, cardio-inhibitory center; *C.A.C*, cardio-accelerator center; *V.C.C*, vaso-constrictor center; *V.D.C*, vaso-dilator center; *E.I*, efferent inhibitory nerve fibers; *E.E*, efferent excitatory; *Ht*, heart; *B.V*, blood vessels. +, increases activity of end organ; −, diminishes activity of end organ. Note: the only difference between the nervous mechanism of the heart and that of the arteries is the absence in the case of the latter of the tonic action of the *V.D.C* and consequently the absence of any afferent inhibitory fibers going to that center.

These relations are shown in the accompanying diagram (Fig. 118).

Capillaries and the Velocity of the Blood. — The most important characteristics of the capillaries are their enormous total area and their thin walls, which are composed of a single layer of flattened cells (Fig. 110). The combined area of the capillaries has been estimated to be 900 times the cross section of the aorta. How this expansion of the blood stream affects the velocity of the blood will now be shown.

Let Fig. 119 represent a river of which the depth is everywhere the same though the breadth varies from point to point. At 2 there is a marked widening of the river while at 3 there is a marked narrowing. Let 1, 2, 3, and 4 be imaginary lines drawn across the stream. It is evident that if a thousand liters of water pass the line 1 in one minute, then one thousand liters must pass the lines 2, 3, and 4 in the same time, for each liter passing in at 1 must replace a corresponding amount flowing out at 2, which in turn replaces another liter flowing out at 3, and so on. It is also evident that if the breadth of 1 and 4 be the same, then the velocity of the flow at 1 and 4 will also be the same. At 3, however, the flow of water must be very swift if a thousand liters are to pass the line 3 in one minute, while at 2 the flow will be correspondingly slow. Of course the same would be true of tubes of varying caliber. In a given time the same amount of liquid would pass by every plane at right angles to the stream, so that where the tube is largest the velocity would be least and where it is smallest the velocity would be greatest.

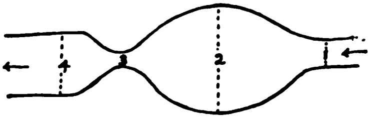

Fig. 119. — Diagram illustrating Leonardo da Vinci's law.

This fact, that the velocity of the moving liquid at any point varies inversely as the cross section of the tube at that point, is known as Leonardo da Vinci's law.

If, instead of an actual enlargement or contraction of the tube, the tube were to break up into many branches (Fig. 120), then the velocity would depend on the sum of the cross sections of the branches. Thus, if the tube *A* breaks up into branches the velocity at *C* depends on the relation of the sum of the areas of the branches to the area of *A*. If the sum be greater the velocity at *C* is less than that at *A*; if equal, equal; and if less, greater.

Let us now see how Da Vinci's law applies to the circulation. After the aorta leaves the heart, it begins to break up into smaller and then into still smaller branches. Now the sum of the cross sections of the smaller branches is somewhat greater than the cross sections of the arteries from which they are derived. And so it is with the branches of the branches, so that as we progress from the aorta towards the capillaries, the bed of the stream becomes wider and wider and the velocity of the blood becomes less and less. This change in the velocity is, however, not very great until the capillaries are reached, where there is a sudden, enormous widening of the stream bed together with a correspondingly great decrease in the velocity of the blood.

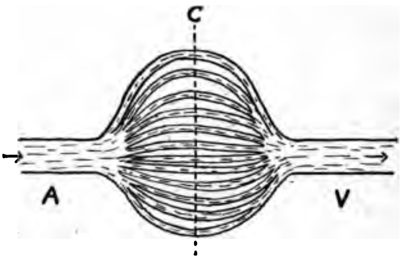

FIG. 120. — Diagram illustrating the application of da Vinci's law to the circulation. *A*, arteries; *V*, veins; *C*, capillaries, the sum of whose cross-sectional areas is greater than that of either *A* or *V*.

The blood from the capillaries is then collected into the veins. As the sum of the cross sections of the veins continually decreases as we proceed towards the heart, the velocity of the blood becomes greater. Since, however, the area of the aorta is less than the sum of the areas of the cavæ, the flow of blood is somewhat slower in the cavæ than in the aorta. The flow in the capillaries is very slow indeed, a fact which, we shall find, is of great importance in the nutrition of the tissues.

The Veins. — As the arteries are characterized by elasticity, the capillaries by multiplicity thereby giving an enormous sectional area, so the veins are characterized by valves (Fig. 121). Owing to the presence of valves, any movement whatever of the blood in the veins must be in a forward direction, *i.e.* toward the heart. The movement of the blood in the veins is brought about in various ways.

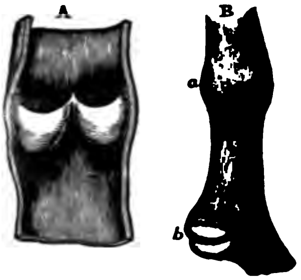

FIG. 121 *A*. — Valves of veins. *A*, vein laid open to show the two pouches of a valve; *B*, unopened vein showing — *a*, the dilatation opposite a valve; *b*, a closed valve seen from the distal side. (Cleland and MacKay.)

1. The pressure exerted by the heart is not entirely spent in forcing the blood through the capillaries. A little pressure still remains to propel the blood back toward the heart again.

2. The contractions of the voluntary musculature exercise a massaging action upon the veins which, aided by the valves, propels the blood toward the heart.

3. Lastly, there is the "aspiratory" action of the thorax, a rhythmic suction resulting from the respiratory movements to which attention will be called later.

The Pulse. — As already stated, with every ventricular systole, the heart discharges a certain amount of blood into the aorta. To receive this blood the distensible aorta dilates, and if we were to place our finger upon this blood vessel we would feel a " pulse." The aorta being not only extensible, but also elastic, immediately begins to contract and in so doing drives the blood onward so that it distends the vessels next to it, which in their turn contract again and so on throughout the arterial tree. In other words, a wave of dilatation, the pulse wave, sweeps over the arterial tree from heart to periphery every time the heart beats. This dilatation is synchronous with the systolic rise in pressure but it is the dilatation and not of course the rise in pressure which is felt. This pulsatile excursion of the arterial wall can be studied graphically by placing an instrument (sphygmograph) upon the artery. In this way, it is seen that the dilatation is rapid, while the collapse is slower and is interrupted by a second smaller elevation (Fig. 122). The second elevation is known as the dicrotic elevation and is of considerable clinical significance.

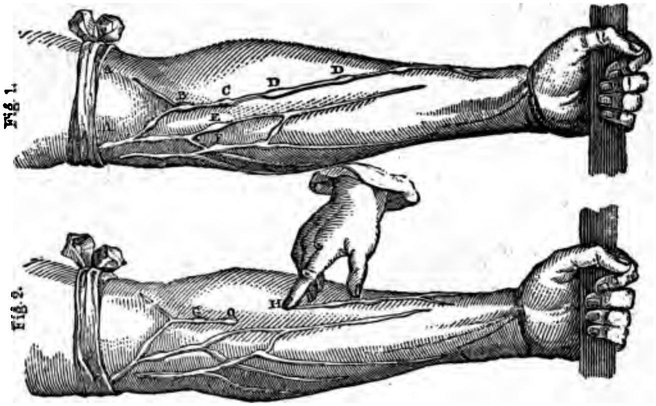

FIG. 121 *B*. — Harvey's illustration showing how the valves of the veins hinder the back flow of the blood in these vessels. "But that this truth may be made the more apparent, let an arm be tied up above the elbow as if for phlebotomy (*A*, *A*, Fig. 1). At intervals in the course of the veins, especially in laboring people and those whose veins are large, certain knots or elevations (*B*, *C*, *D*, *E*, *F*) will be perceived, and this not only at the places where a branch is received (*E*, *F*) but also where none enters (*C*, *D*); these knots or risings are all formed by valves, which thus show themselves externally. And now if you press the blood from the space above one of the valves, from *H* to *O* (Fig. 2) and keep the point of a finger upon the vein inferiorly, you will see no influx of the blood from above; the portion of the vein between the point of the finger and the valve *O* will be obliterated; yet will the vessel continue sufficiently distended above the valve (*O*, *G*)." (Quotation and figure are from Wm. Harvey, "On the Motion of the Heart and Blood in Animals," 1628.)

If we pass from the heart to the periphery, the pulse becomes smaller until in the capillaries it can, as a rule, no longer be observed. If, however, the organ, to which any particular set of capillaries is distributed, is in a state of functional activity, the arteries going to it become dilated. Under such conditions the pulse may not be obliterated by the small arteries but may appear in the capillaries and venules of the organ. From this " venous pulse " we must distinguish the pulse which occurs in the large veins near the heart. The latter is due to changes in the pressure in the right auricle which are transmitted backwards into the veins, since in this region the latter are not provided with valves. This is also called the

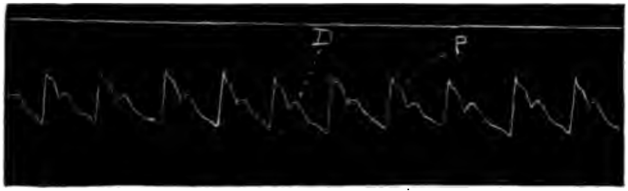

FIG. 122. — Sphygmogram from radial artery. *D*, dicrotic elevation; *d*, dicrotic notch. Note the sudden rise of the curve (due to the increase in the size of the artery) and the much slower fall of the curve (due to the decrease in the size of the artery as the crest of the pulse wave passes the point under observation). (Howell.)

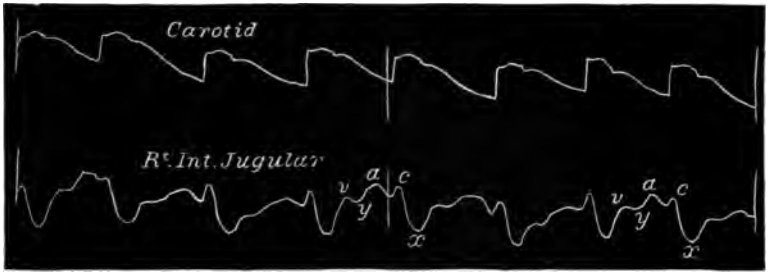

FIG. 123. — Simultaneous tracings of the carotid and jugular pulses. Note the *a* and *c* waves. (Mackenzie.)

" venous pulse " and is of great importance in the clinical study of the heart. For each beat there are three principal waves in the jugular vein, one (*a*) corresponding to the contraction of the auricle and one (*c*) to that of the ventricle (Fig. 123).

CHAPTER VIII

THE RESPIRATION

Introduction. — The essential process in respiration is the interchange of gases between the organism and the surrounding medium. In unicellular organisms, like the amœba, this process occurs with little difficulty, the cytoplasm of the organism being separated from the surrounding medium by only its own cell wall through which the gases readily pass. In the more complex organisms, however, it is necessary, as already stated (page 29), to transport the gases to and from the tissues and consequently a circulation is needed. In fishes, for example, the blood acts as a carrier of the gases to and from the gills for the benefit of the tissues. In still higher animals yet another mechanism is required. Here the capillary area for interchange of gases with the surrounding medium is itself within the body and it is necessary to bring to this area a continuous supply of air that the interchange in question may be carried out. Respiration in man is therefore a threefold process, (1) the ventilation of the lungs, (2) the gaseous interchange between the air in the lung cavities and the blood in the pulmonary capillaries, (3) the gaseous interchange between the blood in the tissue capillaries on the one hand and the lymph of the tissue spaces and the tissue cells on the other.

The Lungs. — The approach to the lungs is through the nasal passages where the inrushing air is warmed, the pharynx which serves as a passage for both air and food, the larynx (the organ of speech), the trachea, which is a membranous tube strengthened and prevented from collapsing by cartilaginous rings which are incomplete behind and therefore C-shaped. The trachea divides into right and left branches, which in turn divide again and again into smaller air passages. The cartilaginous rings become

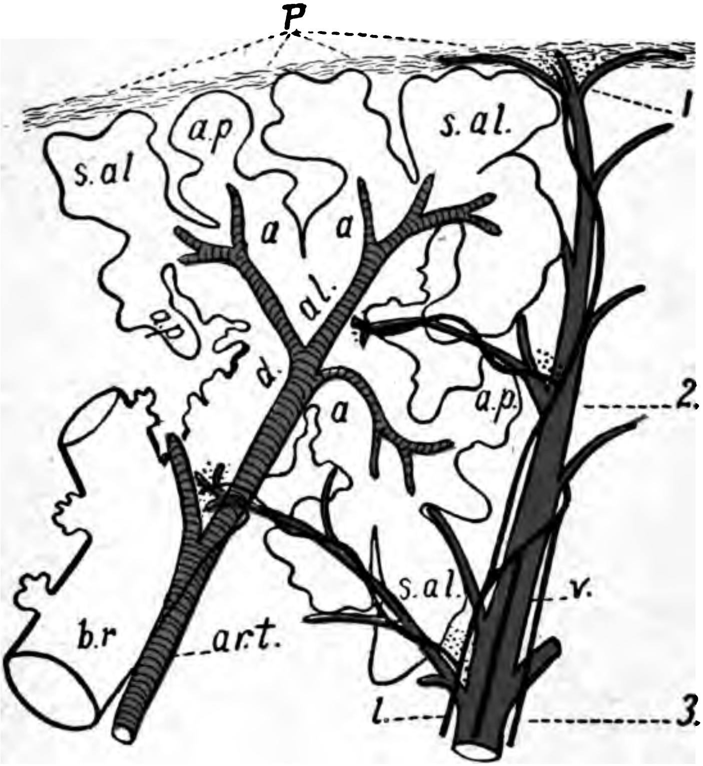

Fig. 124. — Terminations of the bronchi. A bronchiole, *br*, is seen dividing into two alveolar passages or ducts, *d.al*, one of which is completed in the drawing. From this duct the atria, *a*, rise, each of which communicates with a variable number of alveolar sacs, *s.al*, which bear around their periphery the pulmonary alveoli, "air cells," or ultimate chambers of the air passages, *a.p.* *P*, visceral pleura; *Art*, artery; *V*, veins; *l*, lymphatic; 1, beginnings of the veins in the pleura; 2, at the alveolar ducts; 3, in places where the bronchi divide. (Miller.)

thinner and at last disappear while in the smaller bronchioles the circular muscular coat of involuntary muscle is relatively increased. The bronchioles end in thin-walled cavities incompletely subdivided into "air cells" (Fig. 124). In the thin walls of the air cells run the pulmonary capillaries bringing venous blood to be oxygenated. There are also capillaries derived from the bronchial arteries bringing oxygen to the thicker parts of the lung, the bronchioles, bronchi, and so forth.

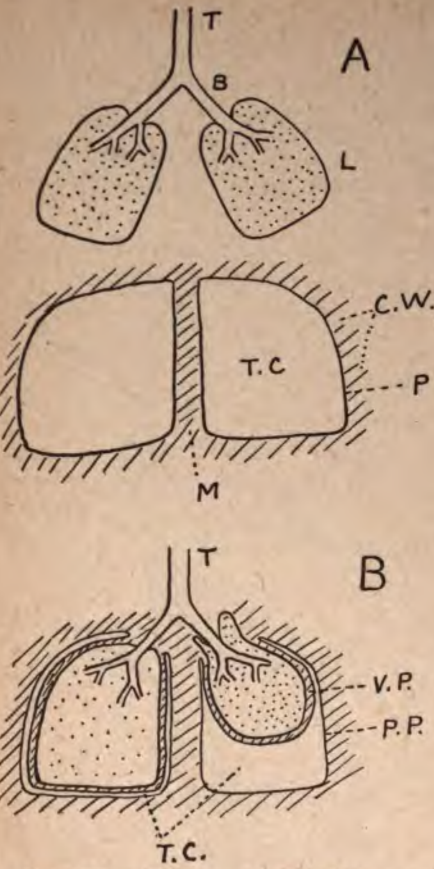

FIG. 125. — Diagram: relation of lungs to pleura. *A* represents above two lungs (*L*), two bronchi (*B*) and a common trachea (*T*). Below these is seen the thoracic cavity (*T.C*), which is divided into halves by the mediastinum (*M*). The thoracic cavity is surrounded by the chest wall (*C.W*) and is lined with a smooth, glistening, moist membrane, the pleura (*P*). In interpreting *B* the student should imagine that the lungs are being pushed through the thoracic wall into the cavity and that as they enter the cavity they drive the pleura in front of them. To the right the lung is seen entering the cavity; to the left the lung has entered and completely fills the cavity. The pleura left undisturbed is the parietal pleura (*P.P*); that which is carried into the cavity by the lungs is the visceral pleura (*V.P*). As the lungs fill the cavity, the latter ceases to be actual and becomes potential. From this purely imaginary proceeding the anatomic relation of the pleura to the lungs is seen to be similar to that of the pericardium to the heart.

The pleura bear the same relation to the lungs that the pericardium does to the heart and the same diagram might serve for both, except that in the case of the heart the cavity is single but is double in the case of the lungs (Figs. 105 and 125).

The trachea and bronchi contain many mucous glands and are lined with ciliated epithelium (Fig. 6). The motion of the cilia is directed toward the mouth so that mucous and small foreign bodies are gradually in this way eliminated from the air passages.

Pressure, Volume, and Density of Gases. — Before discussing the mechanism by which the lungs are ventilated, a short presentation of some of the more important facts in regard to the physics of gases seems advisable.

Among the chief characteristics of gases are their compressibility and their tendency to expand. In the case of solids each molecule is held rigidly in place. In liquids the molecules may move back and forth over one another but the distances between them remain constant; a liter of water is always a liter of water, never any more and never any less. In the case of gases, however, the molecules have no fixed places or even fixed distances in relation to one another. We may compress a liter of gas until it occupies 100 cc. and on relieving the pressure the gas will go on expanding and expanding and filling completely any vessel we choose to put it into, for the molecules of gas actually repel each other. Of course the more the gas expands, the less dense does it become and the more it is compressed the greater becomes its density.

If the molecules of a gas repel each other, they must do so with a certain force, a force which we ought to be able to measure. This force, the force with which the molecules of gas repel each other and by virtue of which the gas as a whole tends to expand, is known as the "pressure" of the gas and it can be measured by means of a mercury manometer placed in connection with the vessel containing the gas. A study of the relation of the volume of a gas to its pressure shows that as we decrease the volume (and consequently increase the density) we cause the pressure to rise (increase), and vice versa. Hence we may say that the pressure varies directly as the density and inversely as the volume. A moment's thought will not only make this matter clear but the facts will appear almost self-evident.

Repulsion and Gravity. — Since the molecules of a gas repel each other, then, theoretically, if a gas be allowed to escape from the vessel containing it, it will go on expanding indefinitely, becoming more and more rarefied. How is it then that the atmosphere which is not inclosed in anything, does not go on expanding indefinitely until its volume has become indefinitely great and its density and pressure infinitely small? The answer is simply this, that the gravitational attraction of the solid earth is such that it prevents the gas from expanding indefinitely.

We can measure the pressure of the atmosphere just as we can measure the pressure of a gas in a closed vessel. All that is necessary is to place the air in connection with a mercury manometer. But if we use a simple U-shaped tube, it is obvious that the atmospheric pressure will act upon both limbs of the tube so that the mercury will stand at the same level in both limbs (Fig. 126 *A*). We can however seal up one end of the tube and fill the whole with mercury. Then on turning the sealed end up as in the figure (Fig. 126, *B*), it will be found that the sealed end will not remain full, for the mercury will fall until the difference in the level of the two limbs is 760 mm. A pressure therefore equal to that of a column of mercury

760 mm. long must be acting from above downwards upon the exposed surface of the mercury. This is the pressure exerted by the atmosphere. The greater the pressure of the atmosphere, the higher the column of mercury; the less the pressure, the lower the column. The instrument ordinarily used in weighing the atmosphere, namely, the barometer, is just such a tube as the one we are describing. In fine weather the air is heavy and " the barometer rises," in wet weather the air is light and " the barometer falls."

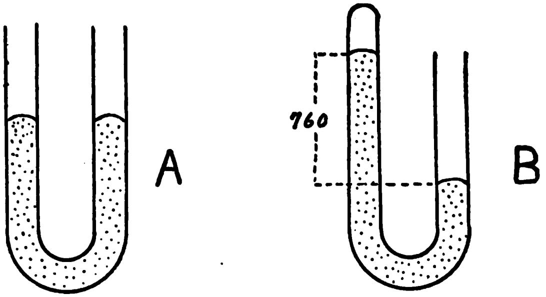

FIG. 126. — Diagrams illustrating the mechanism of the barometer.

The Mechanics of Respiration. — The whole surface of the body is exposed to the atmospheric pressure, and since for the most part the surfaces are not rigid, the pressure is transmitted everywhere throughout the body almost as it would be through so much water. There is, however, one part of the body of which the relation to atmospheric pressure is peculiar. This is the thorax.

The relation of the lungs and of the thoracic cavity to the pressure of the atmosphere is shown in the accompanying diagram (Fig. 127). In the latter the thoracic cavity (*T. C.*) is surrounded by the rigid thoracic wall (*T. W.*). This cavity is larger than the lungs (*L* in position *A*), which are readily extensible and feebly elastic.

The force compressing the thoracic wall from without is 760 mm. of mercury, while the pressure on the inside of *TC* is zero. Still *TW* does not collapse, since it is rigid and strong enough to sustain a pressure of 760 mm. without breaking. The force compressing the lungs while they are outside of the body is also 760 mm. The lungs are not rigid and yet they do not collapse because the atmospheric pressure on the outside is balanced by the atmospheric pressure inside, for the cavity of the lungs is in free communication with the air through the trachea. Now imagine the lungs inside the thoracic cavity. The pressure dilating them is still 760 mm. but the pressure upon the outside of them, that is the pressure within the thoracic cavity, is zero. But since the walls of *L* are extensible, *L* immediately stretches and fills the cavity, taking up the position of the dotted line (*B*) in the figure 127. *L* is not only extensible, however, but also elastic and tends to return to its original size so that it opposes to the distending force a pressure of 3 mm. of mercury. A pressure of 3 mm. cannot balance a pressure

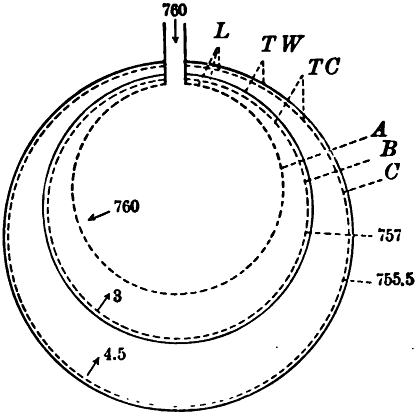

FIG. 127. — Pressure relations in the thoracic cavity. Broken line represents the lungs (*L*); solid line the thoracic wall (*TW*). *A*, natural size of the lungs, that is the size which the lungs would assume when outside of the body. They are then exposed both outside and inside to the same pressure, namely atmospheric pressure, or 760 mm. *B*, position of the lungs and thoracic wall during expiration. Here the pressure of the atmosphere is upon the inside of the lungs only. It presses them against the thoracic wall with a pressure which is equal to atmospheric pressure minus the elastic recoil of the lungs, that is 760 − 3 = 757 mm. *C* represents the inspiratory position.

of 760 mm., of course, but by the time the lungs are stretched to this extent they come into contact with the rigid thoracic walls which add their resistance to the elastic recoil of the distended *L*. If now we increase *TC* somewhat in size, *L* will also increase in size and still fill *TC*. The expanding force is then 760 mm. and the opposing force is the increased elastic recoil, 4.5 mm., together with the resistance of the rigid thoracic walls. The greater the size of *TC*, the greater the distention of *L*. The more we stretch *L* the greater the elastic recoil, so that if we go on increasing *TC* indefinitely one of two things must happen, either *L* will burst or the elastic recoil of *L* will become equal to 760 mm. After that all further increase in the size of *TC* will be without effect on *L*. Such an enormous distention of the lungs of course never occurs. In the position of greatest distention their recoil pressure is rarely more than 30 mm.

Aspiratory Action of the Thorax. — If the lungs were of the same size as the thoracic cavity, then anything situated in the thoracic cavity between the visceral and the parietal pleura would be under a pressure of 760 mm. But we have seen that the lungs are smaller than the thoracic cavity so that they are always stretched and therefore always trying (to the extent of 3 mm. or more) to regain their normal size. Hence anything situated in the thoracic cavity is under less than atmospheric pressure. It is under atmospheric less the elastic recoil of the distended lungs, that is, $760 - 3 = 757$ mm. of mercury. The heart and great veins in the thoracic cavity are, therefore, under a less pressure than the veins in the neck and abdomen which are under the pressure of a full atmosphere. Hence the thorax exerts a suction or aspiratory action on the blood in these veins, a fact which is of great importance in moving the blood towards the heart. (See page 170.)

This suction action of the thorax varies with the distention of the lungs and hence is increased when they are most distended (inspiration) and diminished when they are least distended (expiration).

Muscular Mechanism of Respiration. — The respiratory movements comprise two phases, inspiration and expiration. Inspiration consists in an enlargement of the thoracic cavity by means of the contraction of certain muscles (inspiratory muscles), while expiration is, as a rule, a purely passive act, the enlarged thorax being brought back to its normal position by gravity and by the elasticity of its walls. When the respiration is violent, as; for instance, during suffocation, expiration may become active, *i.e.* it may involve the action of certain muscles (expiratory muscles). The more important muscles of respiration together with their nerve supply and their respiratory action are given in the subjoined table.

NAME OF MUSCLE	ACTION	USED IN	INNERVATION
External intercostals	elevate ribs	normal inspiration	intercostal N.
Diaphragm	depresses floor of thorax	normal inspiration	phrenic N.
Sterno-cleido-mastoid	raises sternum	forced inspiration	XI cranial N.
Internal intercostals	depress ribs	forced expiration	intercostal N.
Abdominal muscles	compress abdominal viscera	forced expiration	lumbar N.

There are two ways in which the thoracic cavity is enlarged by the elevation of the ribs and by the descent of the diaphragm. Normally the latter is more important and in fact during quiet respiration the diaphragm acts almost alone. In many women the elevation of the ribs plays an unduly important part in the respiratory movements. This is owing to vicious dressing and is not a normal sex characteristic. On inspection of the table given above, it will be seen that it contains nothing but voluntary muscles and it is also to be remembered that these muscles have other than respiratory functions. We have here to do with a group of muscles which cooperate in producing the respiratory movements whenever they are not otherwise employed. For example, the diaphragm may be used in compressing the abdominal viscera, the intercostals brace the chest in lifting and the sterno-cleido-mastoid turns the head. At any moment the movements of respiration may be modified or entirely suspended by the employment of these muscles for other than respiratory purposes; soon, however, the normal respiratory movements are quietly, often unconsciously, resumed.

The amount of air that passes in and out on normal quiet respiration is in the adult man about 500 cm.

Inspired and Expired Air.—The important constituents of the air are oxygen, nitrogen, and carbon dioxide. The proportion in which these gases occur in the atmosphere are given below.

	N	O	CO_2
Atmosphere	79	20.96	0.04
Expired air	79	16.02	4.38
		4.94	4.34

In this table the figures represent volumes per cent. That is in every 100 liters of air there are 79 liters of nitrogen, 20.96 of oxygen and only 0.04 of a liter of carbon dioxide. It will also be observed that this table presents not only the volume per cent of the atmospheric air which we inspire but also the volume per cent of the air which we expire. It shows therefore the difference between the inspired air and the expired air, namely, that the amount of oxygen has been decreased by 4.94 volumes per cent and the amount of carbon dioxide increased by 4.34 volumes per cent. Now, if all the oxygen taken into the system was returned to the air again in the form of carbon dioxide, then the volume per cent of absorbed oxygen would equal the volume per cent of carbon dioxide given off, but this is not the case. The oxygen absorbed is more than the carbon dioxide given off. Obviously, then, some of the oxygen must be returned in another form. This is in the form of water vapor, H_2O, the hydrogen with which the oxygen combines being a constituent of the food. Besides this change in the composition of the air inspired, the expired air is found to be saturated with water and warmed almost to the temperature of the body. Thus respiration not only facilitates the exchange of oxygen and carbon dioxide but it also cools the body (cf. p. 251). In those animals which do not sweat, and hence are not cooled by the evaporation of the sweat from the surface of the body, very rapid breathing (panting) occurs, by means of which the loss of heat from the body is increased.

"Impure" Air. — A person entering a badly ventilated room perceives a disagreeable odor, and though he may become somewhat used to this, a long sojourn in such an atmosphere causes headache, depression, and discomfort. What is the cause of this? It is not the presence of carbon dioxide in the atmosphere nor the absence of oxygen, for the changes in the amounts of these two gases are rarely great enough to account for the effects in question. It has been supposed that the expired air contains a poison but there is no conclusive proof for this. At present, the weight of evidence points to the conclusion that the symptoms referred to are due to the heat and moisture of the air which surrounds the body. If the air in the room be kept cool, dry, and especially if it be kept circulating so that the layer of air which is next the body and which has consequently become hot and moist is continually being removed (blown away), the advent of unpleasant symptoms is postponed for a very long time. Not until the carbon dioxide of the inspired air reaches 4 per cent is an increase in the rate of respiration noted, and when it reaches 10 per cent great distress is felt. But these quantities of carbon dioxide are far in excess of those which ordinarily occur even where ventilation is very bad indeed.

Pulmonary Respiration. — It has been stated that the air in its passage through the lungs loses oxygen and acquires carbon dioxide. The mechanism whereby this exchange is brought about depends on several factors. The pressure of the atmosphere is equal to 760 mm. of mercury (see page 178). This atmosphere is made up, as we have seen, chiefly of two gases; nitrogen, to the extent of 79 per cent and oxygen to the extent of 20 + per cent by volume. The pressure of these two gases together equals 760 mm. but of this the nitrogen produces a pressure of about 80 per cent of the whole, *i.e.* 608 mm., and the oxygen 20 per cent of the whole, *i.e.* 152 mm.

If we expose to the air an open vessel full of water a certain amount of the nitrogen and oxygen of the air will become dissolved by the water. If the pressure of oxygen is 152 mm., about 0.393 of a cubic centimeter will be absorbed in 100 cc. of water, and if the pressure of the oxygen be double, the amount dissolved by the water will be double; if the pressure of the oxygen be diminished the amount dissolved in the water will be proportionately decreased. This law of the solution of gases is known as Henry's law. Now, if blood be brought in contact with the air or if it be separated from the air only by a thin moist animal membrane, the blood will dissolve 0.393 cc. of oxygen for every 100 cc. of blood which comes in contact with the oxygen. This is, however, a small amount of oxygen, and if the blood could take up no more than this it would not be very useful as a carrier of oxygen. But as a matter of fact, the blood can take up far more (19 volumes per cent) on account of the respiratory pigment which it contains. The redness of the blood is due to the presence of this pigment which is called hemoglobin and which has the power of taking up large quantities of oxygen. When this is done, the blood becomes crimson. The amount of oxygen which the hemoglobin can take up depends up to a certain point upon the pressure of the oxygen. But when the oxygen has a pressure of 130 mm., the hemoglobin takes up all the oxygen that it ever can. An increase in the pressure above 130 will not cause more oxygen to combine with the hemoglobin, but if the pressure falls below 130 the blood at once begins to give off oxygen, and the more the pressure falls below 130 the more oxygen is given off.

The law of Henry is true of all gases and consequently also of carbon dioxide as well as of oxygen, but, as in the case of oxygen, it is found that more carbon dioxide is present in the blood than can be accounted for by Henry's law. In this case also, the hemoglobin present in the blood combines chemically with the carbon dioxide somewhat as it does with the oxygen and, again as in the case of oxygen, the carbon dioxide is given up again when the pressure of the carbon dioxide surrounding the blood falls.

In the case of the nitrogen the amount absorbed is extremely minute, being only such as would be expected from the law of Henry. Pure nitrogen is moreover a very inert gas chemically and of no importance in the respiratory processes. It is essential to life but only in the form of certain compounds which, as we shall see later, enter the body as food.

Let us see what happens to the air which is inspired into the lungs. The pressure of the important gases of the inspired air is oxygen 152 mm., and carbon dioxide 0.31 mm. The air then enters the lungs and becomes vitiated by admixture of impure air already within the lungs so that the pressure of the gases in the air cavities is now oxygen 100 mm., carbon dioxide 35 mm. The tension of the oxygen in the venous blood is 37.6 mm.; of the carbon dioxide 42.6. So a movement of the gases occurs from the place of higher to the place of lower tension, it is in the direction of the arrow.

	O_2	CO_2
Alveolar Air	100 mm.	35–40 mm.
Membrane	↓	↑
Venous blood	37.6 mm.	42.6 mm.

By the time the blood has passed through the capillaries of the lungs the tension of the oxygen has risen to 100 mm., that of the carbon dioxide has fallen to 35 mm. This is the arterial blood which passes to the tissues. In the tissues it encounters conditions which are the reverse of those in the lungs and the exchange takes place as shown in the diagram.

	O	CO_2
Arterial Blood	100	35
Wall of capillary	↓	↑
Tissues	0	50–70

Cause and Control of Respiratory Movements. — Ordinarily, respiration is a purely automatic act and the coordination of the various muscles is provided for by a center situated in the medulla not far from the vaso-

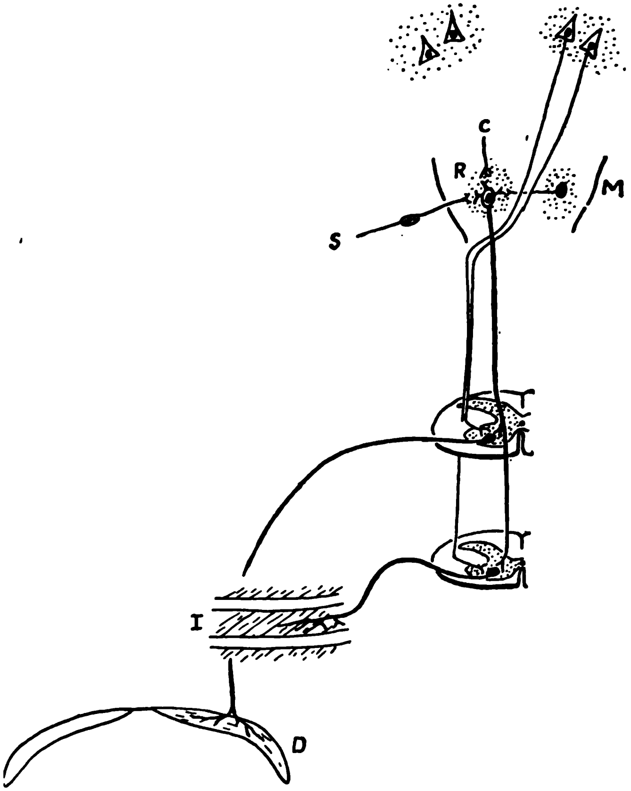

FIG. 128. — Diagram of the nervous mechanism of respiration. *C.C*, cerebral cortex with neurones whose axones pass to the ventral horn cell bodies which supply the voluntary muscles (used for respiration and various other activities). *I*, intercostal muscles; *D*, diaphragm; *R*, one half of the respiratory center in the medulla (*M*), which sends impulses rhythmically to *I* and *D* causing the inspiratory movements. *S*, sensory nerves bringing afferent impulses to the respiratory center; *C*, neurone from cortex to respiratory center which causes at will a suspension of the respiratory movements or may produce an unconscious modification of the movements in the nature of a partial inhibition when some of the muscles usually employed in respiration are required for some other activity.

motor center. The rhythmic action of this center is due to the carbon dioxide in the blood, which acts as a stimulus in arousing the respiratory center. If the carbon dioxide content of the blood be increased the respirations are quickened and deepened (dyspnea); if decreased they become slower and more shallow (apnea). Want of oxygen is likewise, though more rarely, a stimulus to the respiratory activity.

The respiratory center is very sensitive to afferent influences. The afferent nerves may be either inhibitory or excitatory (see Fig. 128). It is a matter of common knowledge that a dash of cold water will cause a marked quickening of the respiration. This is of course due to the stimulation of the afferent excitatory fibers from the skin to the respiratory center. A reduction of the carbon dioxide in the blood not only causes apnea but also a decrease in the irritability of the constrictor center and hence a fall in the blood pressure and a feeble, rapid heart-beat. This is known as acapnea and is thought by some to be the same phenomenon as surgical shock.

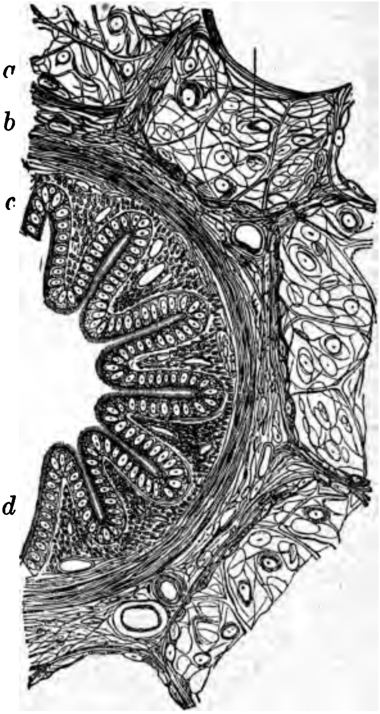

FIG. 129. — Cross section of a small bronchial tube. *a*, fibrous layer; *b*, muscular layer; *c*, mucous membrane in longitudinal folds with numerous longitudinally running elastic fibers cut across; *d*, ciliated epithelium. (Schultze.)

Bronchial Constrictors. — The bronchioles of the lung are provided with a muscle coat (Fig. 129) the contraction of which causes a diminution of the caliber of these air passages. This musculature is supplied with efferent excitatory and inhibitory fibers through the vagus.

The value of the excitatory fibers is doubtless protective. A stimulation of the nasal mucous membrane with some such harmful gas as ammonia will bring about a whole series of reflex acts of a protective nature. Whether the same set of afferent fibers or several sets are called into action is not known, but the results are as if the gas had stimulated afferent excitatory to the bronchial constrictor muscles, afferent inhibitory to the respiratory center, afferent excitatory for the closure of the glottis and afferent excitatory to the cardio-inhibitory center; all of which tend to decrease the intake of the gas into the lungs and blood.

CHAPTER IX

THE BLOOD AND LYMPH

The Blood

The blood is composed of a liquid part called plasma which contains in suspension a multitude of microscopic bodies called corpuscles. The corpuscles are of two kinds, red corpuscles or erythrocytes (to which is due the red color of the blood) and white corpuscles or leucocytes. The blood is normally neither acid nor alkaline but neutral. It contains alkaline salts which normally neutralize the acid products of metabolism until they can be eliminated by the lungs or kidneys.

Hemolysis or "Laking." — The red blood corpuscles are present in normal human blood to the number of 5,000,000 per cubic mm. in males, 4,500,000 in females. These corpuscles contain a red pigment (hemoglobin) which under certain circumstances may pass out of the corpuscles into the surrounding fluid, a process which is known as hemolysis or "laking." Of the numerous ways in which blood may be laked the following are of special interest.

(1) By adding water to the blood.

(2) By adding to it the blood of certain other animals.

(3) By adding to it various toxins such as snake venom or certain products of bacterial activity.

Osmosis and Diffusion. — Let *A* and *B* (Fig. 130, *a*) be parts of the same vessel separated from each other by a partition *C*. Let *A* contain pure water and *B* a solution of sugar in water. Now if the partition *C* be made of muslin, the sugar will pass from *B* to *A* until the solution in the two parts of the vessel is of the same strength. But if partition *C* be made of animal membrane, as, for example, parchment, then it will be found that the sugar will remain in compartment *B*, and not pass over into *A*. The water from *A* will however pass from *A* to *B* so that the height of the water in *B* will be greatly raised (Fig. 130, *b*). This passage of water into *B* is known as osmosis. The level of the liquid in *B* has risen and the level in *A* has fallen and it is possible to measure the amount of this difference between these two levels (*OP*). This difference depends upon the strength of the sugar solution. The stronger the solution the greater is the difference. The difference is known as the osmotic pressure. This osmotic pressure may be very great. The water may rise very high in *B* so that the partition *C* ceases to be able to sustain the pressure and bursts.

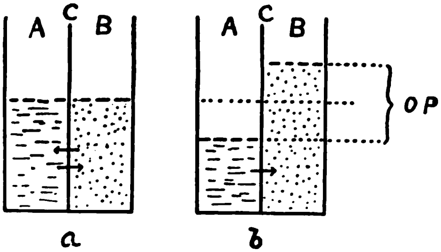

FIG. 130. — Diagram illustrating osmotic relations. *A*, compartment containing water; *B*, compartment containing a solution of sugar; *C*, partition between the two compartments. In *a*, *C* is permeable; in *b*, it is semipermeable. *OP*, difference of level of the liquids when the chambers are separated by a semipermeable membrane, measures the osmotic pressure.

It can readily be seen that if *B* were a plant immersed in water or damp soil (*A*), this water would be absorbed by the plant in proportion to the concentration of the solution of salts contained within the plant. The plant then becomes turgid with the water which has passed into it from the moist soil (*A*). If there were a continuous evaporation from the leaves of the plant then there would necessarily be a continuous flow of water towards the plant to compensate this loss of water through evaporation — Fig. 131.

Let us now substitute for *B* a red blood corpuscle. If a red blood corpuscle be placed in water (*A*) the water will pass through the semipermeable membrane which forms the wall of the corpuscle because of the dissolved salts which the blood corpuscle contains. The amount of water which passes in is proportional to the concentration of the salts contained in the corpuscle. In this case the osmotic pressure is greater than the strength of the membrane, for as the water passes in it swells the corpuscle more and more until the partition, *i.e.* the wall of the corpuscle, bursts and liberates the contents of the corpuscle, including the hemoglobin. It can readily be seen that a solution may have one of three relations to the red blood corpuscle.

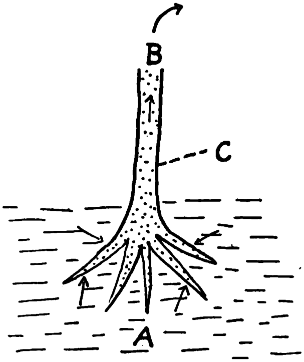

FIG. 131. — Diagram illustrating osmotic relations in plants. *A*, water or moist soil; *B*, plant juices with high osmotic pressures; *C*, wall of plant (semipermeable). Arrows show the direction of flow of water into and up through the plant.

(1) The salts may be dissolved in the solution in concentrations less than those within the corpuscle, (hypotonic solution). In this case the liquid will pass into the corpuscle until laking results.

(2) The concentration of the solution may be greater than that within the corpuscle (hypertonic). In this case the water will pass out from the corpuscle, which consequently will shrivel up.

(3) The concentration of the solution may be equal to that of the salts within the corpuscle (isotonic). The solution then exercises no injurious action upon the red blood corpuscles.

The composition of the blood in salts is as follows:

Sodium chloride	0.900%
Calcium chloride	0.026%
Potassium chloride	0.030%

If therefore we desire to add to blood a solution with which the blood is isotonic we add a solution of the above composition. This is known as Ringer's solution (see p. 151). As a rule, however, the calcium and potassium salts being so small in quantity are omitted and the solution is then known as a physiologic salt solution (*i.e.* 0.9 per cent sodium chloride).

Immunity. — If to the blood of a rabbit be added the blood (or blood serum) of a dog, an hemolysis (or laking) of the red corpuscles will result. There is here no difference in osmotic pressure so that the hemolysis must be due to the special toxic (poisonous) action of the dog's serum. This action is destroyed by heating the serum to 55° C. If, on the other hand, the serum of a guinea pig's blood be used, no such hemolysis occurs. It has however been found that if certain procedures are resorted to the guinea pig's serum will come to show a toxicity to red corpuscles similar to that of the dog's serum, *i.e.* it will hemolyse the corpuscles. The procedure referred to consists in injecting rabbit's blood subcutaneously into a guinea pig. This procedure is known as immunizing, and the serum of the guinea pig made toxic by artificial means is called immune serum. To the particular toxic substance which is developed in the guinea pig's serum the name "antibody" is given and to the substance in the rabbit's corpuscle which causes the development of the antibody the name "antigen" is given.

These facts are given in this detail because the phe[illegible]mena of immunity are similar. It is only necessary to substitute for the rabbit's corpuscles a disease germ and for the guinea pig a patient, as follows: Invading bacteria, produce an antigen which causes the development of an antibody in the body of the host. This antibody is capable of destroying the invading bacteria. Here is the explanation for the spontaneous cure which occurs in such diseases as pneumonia where the patient is rendered immune by the development in his own body of the antibodies. Here also is the explanation of the serum treatment of other diseases, *e.g.* diphtheria. In this case the animal which is immunized is the horse. The serum of the horse with its antibodies capable of destroying the diphtheria bacillus is injected into the human being and the patient is not rendered immune but is *protected* by the serum of the immunized horse. Of course, if no immune serum were injected the patient might recover owing to the formation, in his own body, of antibodies, but the addition of a serum already charged with antibodies materially aids in the fight against the invading organisms. These facts have been summarized in the accompanying table.

Table Summarizing Facts of Immunity

Dog's serum	injected into	rabbit	causes hemolysis
Guinea pig's serum	injected into	rabbit	no effect
Rabbit's serum	injected into	guinea pig	forms antibodies
Guinea pig's serum containing antibodies	injected into	rabbit	causes hemolysis
Diplococcus pneumoniæ	enters	man	forms antibodies
Human blood containing antibodies	circulating in	man	kills diplococcus
Bacillus diphtheriæ	injected into	horse	forms antibodies
Horse's serum	injected into	man	kills bacillus

The Properties of Hemoglobin. — The pigment hemoglobin gives the red blood corpuscles their red color. Iron is an essential ingredient of the hemoglobin. The pigments of the bile and urine are derived from hemoglobin. The most noteworthy property of hemoglobin is this, that it takes up oxygen readily and gives it up again readily. The compound of hemoglobin with oxygen is known as oxy-hemoglobin. This fact may be expressed in the form of the chemical equation as follows:

$$(1)\quad Hb + O = HbO \text{ and}$$
$$(2)\quad HbO = Hb + O$$

In presence of oxygen the first of these processes takes place, but in an environment in which oxygen is scarce the second occurs. If, therefore, the blood stream carries the corpuscles from the place where oxygen is plentiful to a place where it is not, and then back again, it is clear that the corpuscles through the agency of their hemoglobin will carry oxygen from the place where it is plentiful (lungs) to the place where it is not plentiful (tissues), and then having parted from it the corpuscles will return to the lungs for a fresh supply. Oxygen is extremely important in the vital processes. Consequently, the condition of the hemoglobin is important to determine. Such determinations are made clinically by means of two instruments, the hemoglobinometer which indicates the amount of hemoglobin in the given sample of blood and the hemocytometer which indicates the number of red blood corpuscles, that is, of hemoglobin carriers, in the circulation. The change from hemoglobin to oxyhemoglobin is accompanied by a change in color from purple to crimson, and inasmuch as the red blood corpuscles carry hemoglobin in the veins and oxyhemoglobin in the arteries, the arterial and venous blood may be distinguished by the color. Hemoglobin also readily forms a compound with CO_2 (carbohemoglobin), which is readily decomposed again. The equations are

$CO_2 + Hb = CO_2Hb$ where CO_2 is abundant and

$CO_2Hb = CO_2 + Hb$ where CO_2 is deficient.

Consequently, the Hb serves not only as a carrier of oxygen from the lungs to the tissues but also of CO_2 from the tissues to the lungs.

Origin of Red Blood Corpuscles. — In the bone marrow are nucleated colorless cells which multiply continuously. At a certain period hemoglobin begins to appear in the protoplasm of these cells and a little later they lose their nuclei, become typical erythrocytes and pass out into the blood stream. In the course of ten days or so the erythrocytes disintegrate and the pigment part of the hemoglobin is excreted in the urine and especially in the bile.

Leucocytes. — The white blood corpuscles, or leucocytes, are of several varieties. Under normal conditions their number varies from 5000 to 7000 per cubic millimeter. An increase above normal is known as a leucocytosis; a decrease is known as a leucopenia. The leucocytes possess the power of amœboid movement (Fig. 3) by virtue of which they are able to pass through the walls of the capillaries and wander about into the surrounding tissues. The leucocytes appear to have several functions:

(1) They protect the body from foreign cells, bacteria, etc.

(2) They take part in the process of coagulation.

The first is accomplished either by ingesting the bacteria in virtue of their amœboid movement (phagocytic action) or by contributing to the formation of the antibodies. It is further stated that the phagocytic action of the leucocytes depends upon the formation of a certain class of antibodies known as opsonins. In the presence of these opsonins and in proportion to their amount, the leucocytes ingest the invading bacteria. The phagocytic power of any particular blood may be determined by observing the number of ingested bacteria contained in the leucocytes. It is the belief that this power is dependent on the opsonins present, that gives us the term "opsonic index," a term which is practically equivalent to "phagocytic power" or the power of destroying invading micro-organisms.

Clotting.—Among the proteins[1] of the blood plasma is one of especial interest, the fibrinogen, upon which depends the power of clotting which the blood possesses. It is present in only a very small amount. The process of coagulation of the blood is familiar to all. Blood, when it first escapes from the vessels, is perfectly fluid. In a few minutes it becomes viscous and then sets into a soft jelly which quickly becomes firmer, so that the vessel containing it may be inverted without spilling the blood. The clot continues to grow more compact and gradually shrinks in volume, pressing out a quantity of clear, faintly yellow liquid (blood serum). The essential part of the clot is fibrin, an insoluble protein which is derived from the fibrinogen of the normal blood. This fibrin appears as a fine network of delicate threads which shrinking entangle in their meshes the red blood corpuscles and squeeze out the blood serum. Clotting then is the formation of insoluble fibrin, a process which, according to one investigator, takes place in the following manner:

There is present in the blood a substance called thrombogen. When this is acted on by the calcium salts of the blood the resulting substance is thrombin. Thrombin in turn acts upon fibrinogen and the resulting product is fibrin. Now calcium salts, thrombogen, and fibrinogen are all present in the circulating blood but the blood does not coagulate in the vessels. The reason for this is that in addition to the substances already mentioned there is present a substance (antithrombin) which prevents the formation of thrombin by the interaction of calcium and thrombogen. When, however, blood is shed there is a disintegration of the cellular elements (tissue cells and leucocytes) with the formation of a substance or substances which neutralize antithrombin and thus permit first the formation of thrombin and secondarily the formation of fibrin. The time required for blood to clot varies according to the conditions under which it is kept. If it is received in vessels coated with vaseline, the white blood corpuscles disintegrate very slowly and consequently the clotting is slow. The same result is obtained by bleeding into cold vessels which are kept in a cool place. Or by chemical means the calcium can be removed from the blood as soon as it is drawn and such blood will, of course, be incoagulable. On the other hand, if the blood is received in a gauze sponge its white blood corpuscles disintegrate very rapidly and consequently the coagulation is hastened. These facts are represented in semidiagrammatic form as follows:

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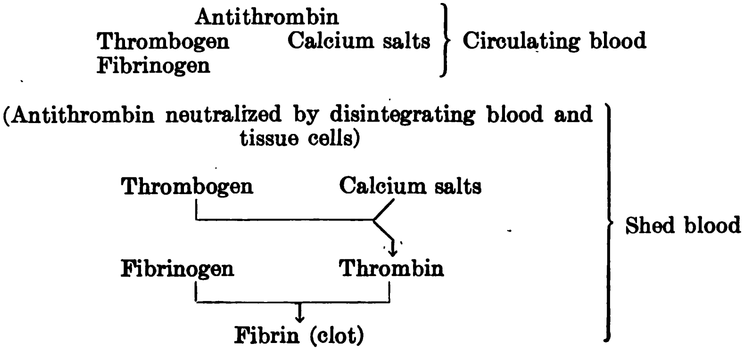
[1] The origin, function, and destination of the other proteins of the blood are but little understood.

Semidiagrammatic View of the Clotting of Blood



The weight of blood amounts to about 7.6 per cent of the total weight of the body.

The Lymph

Authors have stated that the cells of the body lie bathed in an extravascular lymph "like fishes in water." This, however, gives an erroneous idea of the size of the intercellular spaces. A better simile would be "like sardines in oil" or "like canned fruit in its juice." This juice corresponds to the extravascular lymph. Between these cells pass the blood capillaries and among them are thrust the ends of the lymph capillaries. From the extravascular lymph the cells take what may be needed for their life and functional activity and to it they return the waste products of their metabolism.

If now we consider any small portion of blood we find that to leave the capillaries it has one of two courses to take, either (1) to pass directly into the veins or (2) to pass through the capillary walls, to add itself to the extravascular lymph. Obviously, to the red blood corpuscles only the first of these possibilities is open, but to all the other constituents of the blood, including the oxygen of the red blood corpuscles, the possibility of passing through the blood vessel walls is present. Whether they shall pass through at any particular time or place depends upon various circumstances. Among these is high blood pressure, which favors filtration, so that other things being equal the amount of plasma filtering through the blood vessel walls is increased with increase of blood pressure. There are also the osmotic and diffusion relations of the blood (see p. 191) and the extravascular lymph which affect the passage from the blood vessels into the tissue spaces. For example, the absence of any free oxygen in the extravascular lymph causes a diffusion of the oxygen out from the blood vessels, or again the presence of large amounts of salts in the tissue spaces would cause an osmotic flow of liquid into the tissues from the blood, if the vessel walls are impermeable to the salts in question or not very permeable to them, or if the production of the salts was a sudden process.

On the other hand, substances in the extravascular lymph have two paths away from the tissues, by way of the blood vessels and by way of the lymphatics, and which course will be taken depends on various osmotic and diffusion conditions. If the extravascular lymph passes into the lymphatics and thereby becomes intravascular lymph, it gradually finds its way from the lymph capillaries into the larger vessels, which resemble veins in structure, and so on to the thoracic duct which empties into the left subclavian vein, or to the right lymphatic duct which empties into the right subclavian vein. These relations are shown in the accompanying diagram (Fig. 132). The circulation of the lymph is carried on by factors similar to those which move the venous blood. At the end of the system in the turgid tissues, the pressure is high, at the

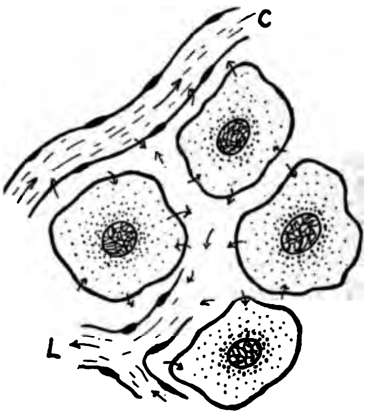


FIG. 132. — Diagram showing the relation of the cells to the blood and lymph capillaries. The cells lie in the "intercellular" spaces which are filled with lymph. Through these spaces among the cells run the blood capillaries (*C*) and here also are the open (?) ends of lymphatics (*L*). The direction of movement of the liquids and dissolved substances is indicated by the arrows.

other end (the veins) the pressure is low and consequently the flow toward the veins takes place. This is further influenced by the combined action of the valves in the vessels and the muscular movements; the latter squeezing the lymph along, the former obliging it to go in one direction only.

CHAPTER X

DIGESTION

Introduction. — To the superficial observer at least, the nutrition of the amœba is a very simple matter. When this organism encounters a particle of food a temporary mouth is formed and thrust around the particle in question; in front of the particle a temporary gullet then appears down which the particle passes and comes to lie in a temporary stomach. Into this receptacle the digestive juices pass, the food is in part dissolved and absorbed and the rest, that which is insoluble in the digestive fluids, passes along a temporary rectum to a temporary anus and is left behind as the amœba moves on. The absorbed food then passes through a series of transformations which constitute the vital processes and is finally eliminated from the surface of the organism as waste matter.

In more complex organisms such as ourselves there are involved in the course of these events five separate groups of phenomena.

(1) Purely mechanical activities for grinding, mixing, and transporting the food.

(2) Chemical processes for dissolving and chemically simplifying the food — digestion.

(3) Physical-chemical processes of absorption of the dissolved foodstuff.

(4) The chemical and physical processes by which the food is built up into tissue and later broken down or is

immediately broken down so that its potential energy may be utilized — metabolism.

(5) Elimination of waste products — respiration and excretion.

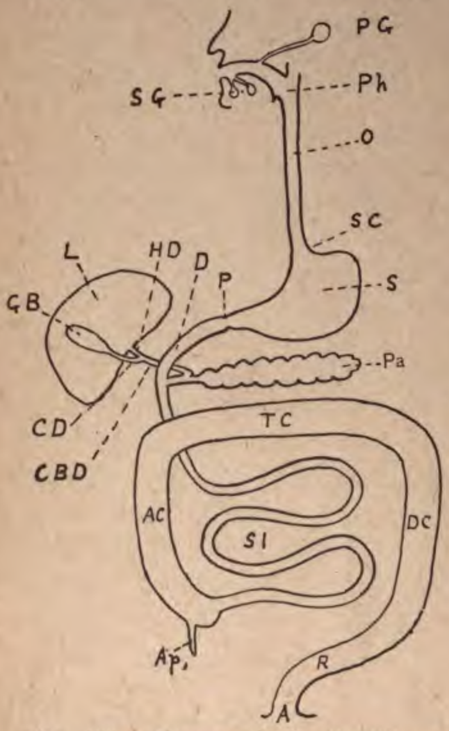


FIG. 133. — Diagram showing the different parts of the alimentary canal and the glands opening into it. *A*, anus; *AC*, ascending colon; *Ap*, appendix; *CBD*, common bile duct; *CD*, cystic duct; *D*, duodenum; *DC*, descending colon; *GB*, gall bladder; *HD*, hepatic duct; *L*, liver; *O*, œsophagus; *P*, pyloris; *Pa*, pancreas; *PG*, parotid gland; *Ph*, pharynx; *R*, rectum; *S*, stomach; *SC*, cardiac orifice of stomach; *SG*, submaxillary and sublingual glands; *SI*, small intestine; *TC*, transverse colon.

The structures referred to as temporary in the amœba are, of course, permanent in complex organisms, and for a brief description of them the reader is referred to the accompanying diagram (Fig. 133). So important are the processes which have been enumerated under the five headings that they will be considered separately in some detail.

Movements of the Alimentary Canal

Mastication. — On being received into the mouth the food is (or should be) thoroughly ground up by the teeth and mixed with saliva. The latter has two functions, the obvious one of facilitating swallowing, and the less obvious but very important one, that of digesting carbohydrates.

Swallowing. — The character of the act of swallowing depends upon the nature of that which is swallowed. Liquids are shot down the œsophagus by the sudden and strong contractions of the muscles of the mouth and pharynx, but solids pass down the œsophagus by the peristaltic action of the muscles of the œsophagus.

Peristalsis. — Peristalsis occurs in such tubular viscera as the œsophagus, intestine, ureters, etc., which possess a muscle coat of circular fibers. Let us suppose for the sake of ease of description that the tube is made of a series of segments A, B, C, D, etc. Now the nature of peristaltic contraction is this. First A relaxes, next B relaxes but A strongly contracts. Then C relaxes and B contracts, and so on. In this way the contents of the tube are driven along from A to D. The characteristics of peristaltic action are (1) there is a wave of relaxation followed by a wave of contraction which passes along the tube, (2) the direction is always the same, (3) the action is under nervous control (Fig. 134).

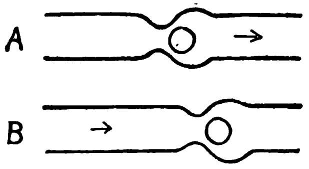


Fig. 134. — Diagram illustrating peristaltic movement. Here are shown a foreign body, *e.g.* a bolus of food, lying in a tubular organ. The foreign body is being propelled in the direction of the arrows, being pushed ahead by a constriction of the tube and coaxed forward by the dilatation of the tube. *A* and *B* are successive stages in the progress of the foreign body, which is preceded by a ring of dilatation and followed by a ring of constriction.

Gastric Movements. — The stomach consists of three parts, the fundus, or part near the opening of the œsophagus, the pyloris or part near the opening into the duodenum and the prepyloric region between them. During digestion at intervals of about 20 seconds peristaltic waves of contraction pass over the prepyloric and pyloric regions and drive the food against the pyloric opening.

The latter, however, remains closed except at intervals when it relaxes to allow the liquid contents of the stomach to pass into the duodenum and contracts again when the acid stomach contents come in contact with the mucosa of the duodenum.

The fundus does not take part in the peristaltic contractions, but by remaining in a condition of tonus it crowds the food to the pyloric and prepyloric regions where it is thoroughly mixed and reduced to a pulp before the opening of the sphincter allows it to pass and thus make room for more food in the pyloric and prepyloric regions.

There is some evidence that the readiness with which the pylorus opens is influenced by the character of the food. Carbohydrates pass quickly out of the stomach but fats remain a long time in the stomach and the transit of foods mixed with fats is greatly delayed.

Like the heart and the respiratory center, the stomach is an automatic organ but is under the control of the central nervous system. The vagus carries motor fibers to both stomach and sphincter pylori, while the sympathetic nerves carry inhibitory fibers to these regions.

Intestine. — The normal peristaltic contractions of the intestine are gentle. A weight of from five to eight grams will stop the movement of any bolus of food and will set up violent, colicky contractions. The average time required for food to traverse the small intestine is about four and a half hours.

The perfect coördination of the peristaltic movements is probably due to nervous action, reflex action; the nerve centers involved are not, however, in the central nervous system. They are in the wall of the intestine itself. This is, therefore, a peripheral reflex. It is probable that a similar mechanism operates in the case of the stomach.

Besides the peristaltic movement there are also rhythmic movements, which consist of a series of local constrictions occurring in those parts of the intestine where masses of food lie. These movements pinch the food into a series of beads (Fig. 135). The musculature of the small intestine and of the greater part of the large intestine receives its nerve supply from the vagus and sympathetic; the motor fibers are chiefly in the vagus, the inhibitory in the sympathetic. The latter come chiefly from the lower dorsal spinal nerves and pass to the cœliac ganglion (Fig. 81), whence they are distributed.

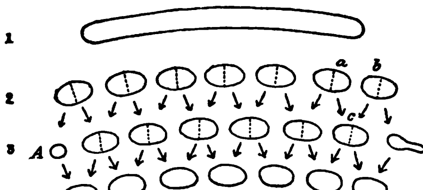


FIG. 135. — Rhythmic segmentation. Diagram to show the effect of the rhythmical constricting movements of the small intestine upon the contained food. A cylinder of food (1) is divided suddenly into a series of segments (2); each of the latter is again divided and the process is repeated a number of times (3 and 4). Eventually a peristaltic wave sweeps these segments forward a certain distance and gathers them again into a long cylinder, as in (1). The process of segmentation is then repeated as described above. (Cannon.)

The stimulus which calls into action the intestinal movements is normally the presence of the bolus of food and is therefore a mechanical stimulation. Such gases as marsh gas (CH_4) and hydrogen sulphide (H_2S), also organic acids and so forth, may act as chemical stimuli when present in the intestine.

The contractions of the cæcum and the ascending colon drive the food toward the valve of the colon and are consequently acting in the direction opposite to that of the peristalsis in the rest of the intestine. This movement is known as antistalsis and serves to delay the food until most of its liquid is absorbed. The intestinal contents, which are semiliquid in the small intestine, are consequently of much firmer consistency in the large intestine.

Defecation. — Defecation is a complex act comprising voluntary and involuntary elements. The former consists in raising the intra-abdominal pressure by contraction of the diaphragm and of the abdominal muscles. The diaphragm is also assisted by filling the lungs with air and then closing the glottis. Any movement of the diaphragm upwards is therefore checked by the lungs which act as cushions of compressed air. The raising of the intrathoracic pressure which occurs during straining with closed glottis retards the return of the blood from the head and arms to the heart. This increase of intra-abdominal pressure is accompanied by a voluntary relaxation of the external sphincter. The involuntary part of these complex movements consists in the relaxation of the internal sphincter and the peristaltic contraction of the rectum. This complex act is the more interesting in that it is one of a number of closely allied and equally important phenomena. In parturition the abdominal muscles, diaphragm, and the muscles which close the glottis act in conjunction with the peristaltic movement of the uterus to expel the fetus. In coughing the same voluntary muscles are employed to elevate the pressure in the lungs so that when the glottis is suddenly opened the air is expelled in a sudden blast — we cough — carrying with it the irritant which we seek to dislodge or expel. In lifting, the same voluntary muscles are brought into play when the weight of the object lifted tends to compress the chest. Here the lungs are filled with air, the glottis closed, and the diaphragm driven up or held up by the contraction of the abdominal muscles.

In all these procedures (except in normal defecation which is not a strenuous act) the high intrathoracic pressure retards the return of the blood from the head and arms to the heart and consequently we may have a more or less pronounced dilation of the veins of these parts during labor pains, severe coughing, heavy lifting and difficult defecation (Fig. 136).

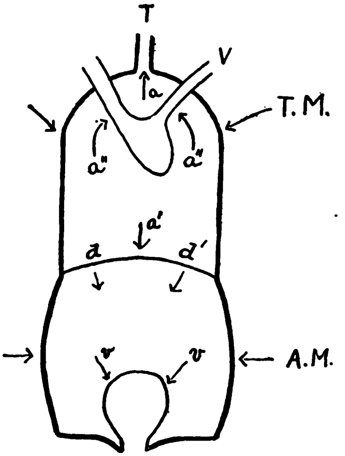


FIG. 136. — Diagram illustrating changes of pressure during straining. *T*, trachea, closed during straining; *T.M*, thoracic musculature compressing the chest; *a*, air in lungs compressed by *T.M*. and reacting (*a*) against glottis, (*a''*) against the great veins entering the thoracic cavity, (*a'*) against the diaphragm (*dd'*). *dd'*, diaphragm compressing the viscera downward. *A.M*, abdominal musculature compressing the viscera and with the aid of *dd'* driving them at *vv* against the hollow organ (uterus, bladder, rectum) and assisting in the expulsion of the contents of that organ.

Foodstuffs and Enzymes

Foodstuffs. — The many different sorts of food are made up of certain elements known as foodstuffs which are usually mixed together in various proportions. These foodstuffs are five in number: Water, inorganic salts, proteins, carbohydrates, and fats.

Enzymes. — Of these foodstuffs only the first two can be absorbed unchanged. The rest have first to undergo chemical alteration to a greater or less degree. These changes (digestion) are accomplished through the action of substances called enzymes which are contained in the digestive juices. The action of an enzyme is similar to a process known to chemists and called by them catalysis. A catalyzer is a substance the presence of which hastens a chemical action which would otherwise occur very much more slowly or not at all. Apparently the catalyzer itself plays no part in the chemical reaction. For example, hydrogen and oxygen when heated combine to form water. At ordinary temperature this combination will not occur and a mixture containing these two gases will remain indefinitely uncombined, but if we place in the vessel containing the mixture of the two gases some spongy platinum the oxygen and hydrogen will at once unite to form water. In this chemical reaction the spongy platinum is not used up any more than the glass vessel which contains the gases. In this case the spongy platinum acts to facilitate a chemical combination, but there are also examples of catalyzers which assist in chemical decomposition. Thus hydrogen-peroxide (H_2O_2) ordinarily decomposes slowly into water and oxygen, but if a little very finely divided platinum be added to the peroxide, say one part in one hundred million, the decomposition of the peroxide into water and oxygen becomes rapid.

Some enzymes have the power of promoting a chemical decomposition under certain circumstances and under other circumstances will cause a chemical recombination of the products of its previous disintegrating action. This is known as reversibility. An excellent example of reversibility is the action of the enzyme lipase, which, under certain conditions, decomposes fat into glycerine and fatty acids and under other conditions causes a recombination of these elements to form fat again. The enzyme which causes the decomposition of one foodstuff (for example, starch) is not known to assist any other decomposition. Each enzyme has its own peculiar activity in this respect; it will facilitate a certain chemical reaction but no other. This peculiarity is known as its specificity.

Some enzymes are formed by the action of two substances not themselves enzymes; of these one is known as the zymogen and the other the activator or kinase. For example, cells of the pancreas secrete a zymogen known as trypsinogen, while the cells of the intestine secrete another substance, a kinase known as enterokinase. These two substances form a third substance, trypsin, which is an enzyme capable of splitting up protein food stuffs. Some enzymes act better in the presence of other substances which are therefore called co-enzymes. Lipase, for example, will split fat more readily in the presence of bile salts. All enzymes are readily destroyed by heating.

To summarize the properties of enzymes: Their action is catalytic and it may be reversible, they are specific, they may be secreted in active form or as a zymogen which must be activated by an activator or kinase, they may work best alone or in company with a co-ferment, they are easily destroyed by heating.

Salivary Digestion

Glands. — When the food enters the mouth it comes in contact with the saliva, the secretion of the salivary glands. Three pairs of these glands discharge their secretion into the mouth, namely the parotid, the submaxillary, and the sublingual glands. The parotid gland communicates with the mouth by a large duct which opens upon the inner surface of the cheek opposite the second molar tooth of the upper jaw. The submaxillary gland lies below the lower jaw, and its duct opens into the mouth cavity at the side of the frenulum of the tongue. The sublingual gland lies in the floor of the mouth to the side of the frenulum and opens into the mouth cavity by a number (eight to twenty) of small ducts. The accompanying simple diagram will show the anatomic relations of the glands.

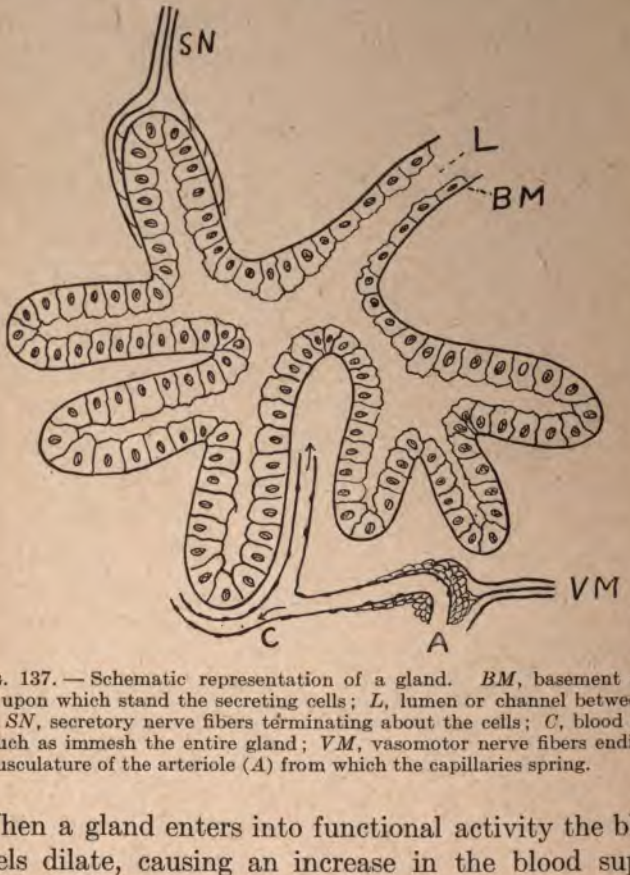


FIG. 137. — Schematic representation of a gland. *BM*, basement membrane upon which stand the secreting cells; *L*, lumen or channel between the cells; *SN*, secretory nerve fibers terminating about the cells; *C*, blood capillary such as immesh the entire gland; *VM*, vasomotor nerve fibers ending in the musculature of the arteriole (*A*) from which the capillaries spring.

When a gland enters into functional activity the blood vessels dilate, causing an increase in the blood supply of the organ; impulses also pass along the fibers to the gland cells, which are thereby stimulated to functional activity, that is, they begin to secrete. The secretion is poured out by the cells into the lumen and as more and more is produced it is gradually crowded toward the duct, along which it is pushed by the continuing secretory activity of the cells behind until it emerges upon the free surface.

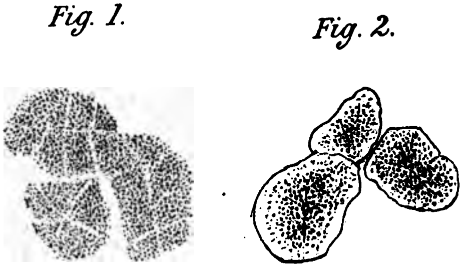


FIG. 138. — Parotid gland of rabbit. 1, fresh resting gland; 2, the same gland 1¾ hours later, after 3.6 cc. of saliva had been obtained by injecting pilocarpin. (Langley.)

The changes which the cells undergo during the process of secretion may be observed with the microscope (Fig. 138). The cells in a resting gland are full of granules. As secretion proceeds these granules become fewer and fewer, being evidently used up in the formation of the secretion. After the period of active secretion is past the granules begin again to appear in the cells.

Nervous Mechanism of Secretion. — The secretion of saliva is a reflex act. The points at which the sensory stimulus may be applied are numerous. It may be the eye, as when we see an agreeable food and the "mouth waters"; and the same effect may be brought about by the smell or even the thought of food. The impulse thus started passes to the centers and thence emerges along the secretory fibers to the salivary glands and also along the vaso-dilators to the gland. The former cause the glands to enter into functional activity, the latter by increasing the blood supply facilitate the work of the gland, bringing to the cells oxygen, water, and foodstuffs and carrying away the waste products.

Such reflexes are known as psychic reflexes, since they involve a cortical or mental process, namely, the recognition that the stimulus coming from the eye or nose indicates agreeable food. A stimulus applied to the taste buds in the mucous membrane of the mouth and recognized as due to a favorite article of food would also call forth a psychic reflex. Other stimuli applied to this region will cause the production of saliva irrespective of any recognized relation to agreeable food. The act is quite independent of consciousness and is therefore a reflex of the ordinary type, where the impulse passes to the subcortical center and returns along the vasomotor and secretory axones. The difference between the ordinary and psychic reflexes will become clearer when we come to consider the gastric secretion.

Ptyalin. — The salivary secretion has as its most important constituents water, mucin (a mucilaginous material), and ptyalin (an enzyme).

The saliva has a digestive action only upon starchy foods. In the presence of the ptyalin, the starches take up water, and split into maltose and dextrin (Fig. 139). If the saliva is well mixed with the food, digestion may be continued after the food has been swallowed, for although the acid gastric juice prevents the action of ptyalin, yet the conditions in the stomach are such that it may be some time before the gastric juice permeates the food and puts an end to the activity of the ptyalin. The action of ptyalin upon the food is facilitated by boiling the latter. Boiling breaks open the indigestible (cellulose) covering of the starch granules and boiled starch is digested in a few minutes while the unbroken granules may resist the action of ptyalin for several hours. The action of ptyalin is greatly affected by variations in the temperature. At 0° C. it fails to act. Above this temperature the action gradually increases until an optimum is reached at 40° C. After this the action gradually declines until at 65° C. the enzyme is destroyed.

The saliva has therefore three uses: (1) it lubricates the food so that it may be swallowed the more easily, (2) it saturates it with water which is a necessary preliminary for any chemical action to take place, (3) it adds to it an enzyme capable of splitting starches.

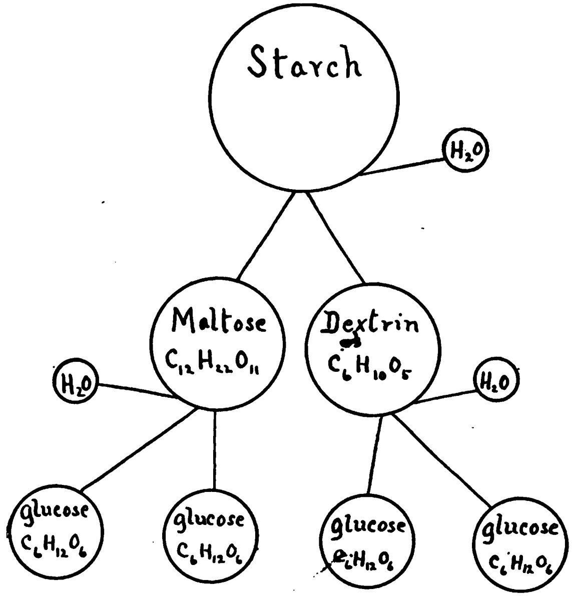


FIG. 139. — Diagrammatic representation of carbohydrate digestion. The first decomposition is accomplished through the action of salivary diastase (ptyalin) or pancreatic diastase (amylopsin); the second decomposition requires another sort of enzyme, the sugar inverting enzymes of the intestine.

Digestion and Absorption in the Stomach

Gastric Juice. — The mucous membrane of the stomach is everywhere permeated by tubular glands (see Fig. 140). Those in the pyloric region secrete only pepsin and rennin, while those of the rest of the stomach secrete not only pepsin and rennin but also hydrochloric acid. The methods employed for obtaining and studying this secretion have become progressively more satisfactory. At first such procedures as swallowing a sponge on a string or feeding such a sponge to a dog were resorted to.

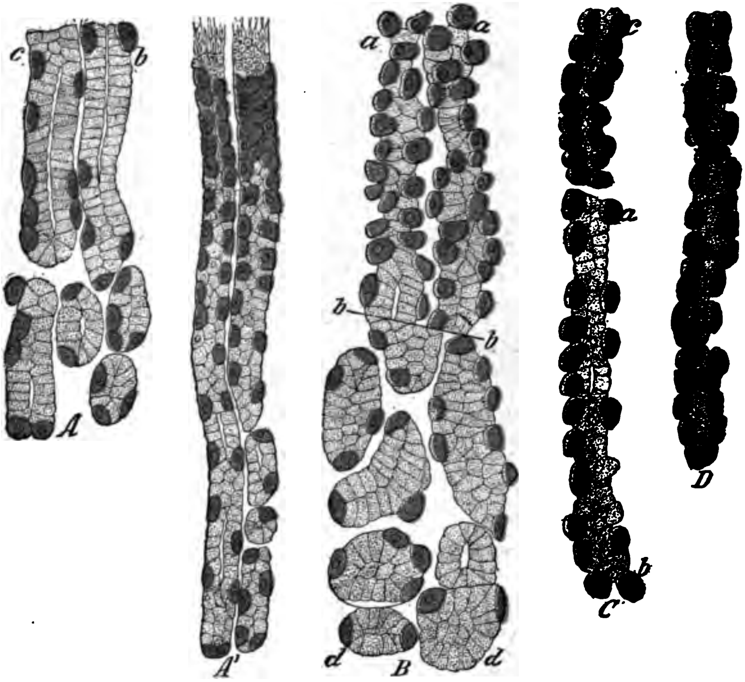


FIG. 140 *A*. — Glands of the stomach of a dog. *A* and A^1 during hunger, resting condition; *B*, shortly after the beginning of digestion; *C* and *D*, later on in digestion. Note the decrease in size of the cells (those not stained red) which secrete the pepsin. (Heidenhain.)

The sponge was later drawn up, squeezed out, the liquid studied. Later Dr. Beaumont had the opportunity of studying the gastric juice and digestion of a Canadian trapper who, by an accidental discharge of a gun, had a permanent opening blown into his stomach. This suggested the production of similar conditions upon animals and a great deal of information was gained in this way. Finally, in the present era of anæsthesia and asepsis it has been found possible to perform more elaborate operations upon animals, such as rarely or never occur in human beings as the result of accident or surgical procedures.

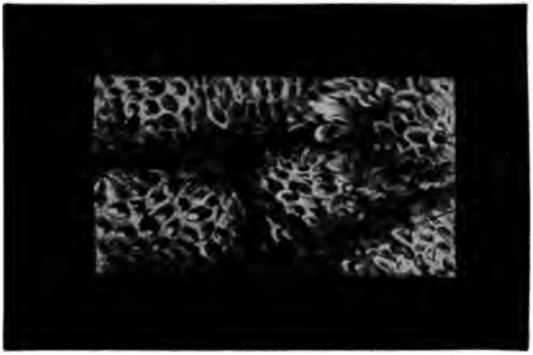


FIG. 140 *B*. — Surface view of mucous membrane of stomach, showing gastric pits into which the glands open. (Spalteholz.)

The normal gastric juice is a thin, colorless, or nearly colorless liquid. Its important constituents are hydrochloric acid (HCl), two enzymes, namely, pepsin which acts on proteins, and rennin which acts on casein. Owing probably to the presence of hydrochloric acid (HCl) the gastric juice does not putrefy and will moreover preserve objects placed in it which would otherwise putrefy. The hydrochloric acid of the gastric secretion is derived from the chlorides of the blood, of which by far the most important is sodium chloride (common salt). It is found that when the diet is deficient in salt the gastric juice is correspondingly deficient in hydrochloric acid.

As in the case of the salivary glands, so also the secretion of the gastric glands is under nervous control. Among the nerves supplying the stomach is the tenth cranial nerve or vagus. Stimulation of this nerve causes a secretion of gastric juice. That this action is a reflex has been shown by Pawlow in the most interesting way. If the œsophagus is cut at the neck so that the food swallowed cannot reach the stomach at all, but is returned to the outer world through the hole in the œsophagus, the animal is said to receive a sham or fictitious meal. Under such conditions it is found that an abundant secretion of gastric juice occurs, but only when the vagi are intact. The action is a reflex from the mouth and nose, where the sensory endings of the taste and smell nerves are stimulated by the food.

Chemical Mechanism. — Besides this psychic secretion there is a secretion due to certain chemical constituents of the food. Some foods do not contain these substances, *e.g.* bread and white of egg; some do, *e.g.* meat extracts, juices, and soups. The products of the digestion of the first class of substances all produce a secretion chemically. These chemical substances are called secretogogues because they cause secretion. They probably act by being absorbed into the blood stream and thence stimulate chemically the secreting cells. The ways therefore in which the gastric mucous membrane may be caused to secrete are (1) psychic secretion, (2) secretogogues contained in the food, (3) secretogogues derived from digestion of food.

Digestive Action. — Pepsin acts only in an acid medium. Its action is retarded by low temperature, the optimum being 37° to 40°. The optimum acidity lies between 0.2 and 0.5 per cent.

The action of the pepsin and hydrochloric acid is to hydrolyze protein. This means that the protein molecule takes up H_2O, then splits into two smaller molecules. This process is repeated several times, so that the end

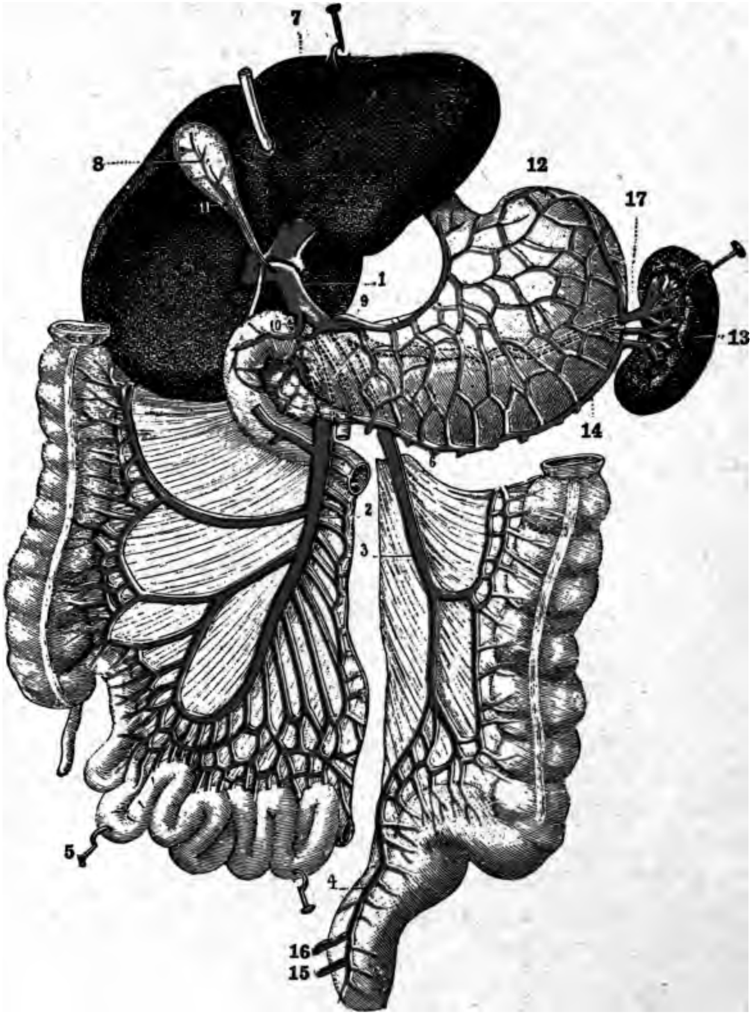


FIG. 141. — The portal system. 1, portal vein; 2, superior mesenteric; 3, inferior mesenteric; 4, superior hæmorrhoidal; 5, small intestine; 6, right gastroepiploic; 7, liver; 8, gall bladder; 9, coronary vein of stomach; 10, pyloric; 11, cystic; 12, stomach; 13, spleen; 14, left gastroepiploic; 15, inferior hæmorrhoidal; 16, middle hæmorrhoidal, which with the preceding vein empty into the hypogastric and this in turn along with the iliac into the vena cava; 17, splenic vein. (Testut.)

products are very much simpler bodies, known as peptones. Under appropriate conditions this process may go on still farther, with the formation of still simpler substances known as peptoids or polypeptids. About 48 per cent of the proteins ingested undergo digestion in the stomach.

The gastric juice also contains rennin, an enzyme which causes the coagulation of milk. This is the substance used in the making of junket. Milk may be coagulated also by acid, as in the formation of clabber.

Absorption. — Relatively little absorption takes place in the stomach. Water (when taken alone), proteins, and fats are not absorbed. Sugars are absorbed, but not readily. The mechanism of absorption is but little

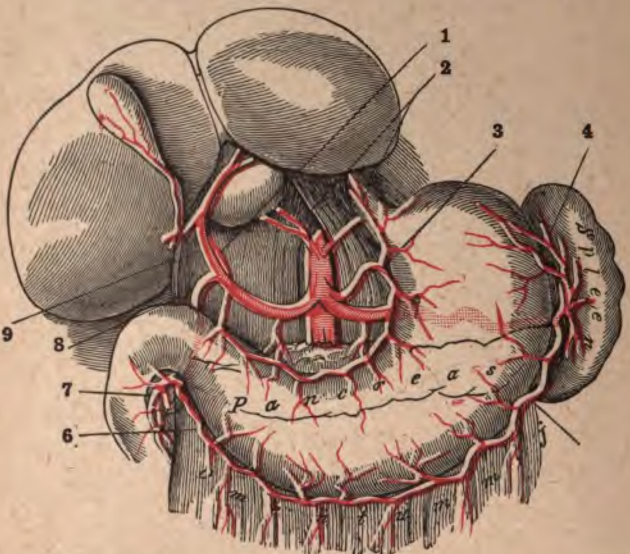


Fig. 142 *A*. — The arteries of the stomach and adjacent organs. 1, hepatic artery; 2, inferior phrenic; 3, left gastric; 4, short gastric branches; 5, left gastroepiploic; 6, right gastroepiploic; 7, pancreatic-duodenal; 8, gastroduodenal; 9, common bile duct. (Gegenbaur.)

understood. In some way the products of digestion pass in solution through the lining of the stomach and into the blood stream. They are then carried by the portal vein to the liver.

The position and mutual relations of the stomach and adjacent organs is seen in Figs. 141 and 142, which also show the blood supply. In Fig. 141 are shown the arrangement of the veins whereby absorption occurs. These veins join the portal vein which terminates in the liver capillaries.

Intestinal Digestion and Absorption

Pancreatic Secretion. — The main duct of the pancreas opens into the duodenum, together with the common bile duct, about eight to ten cm. beyond the pylorus. The cells of this gland contain numerous granules. During secretion these granules are dissolved and discharged into the lumen. They are the zymogens, the material from which the enzymes are made. The pancreatic secretion is strongly alkaline owing to the presence of sodium carbonate. It is of a watery appearance and is secreted in quantities of 500 to 800 cc. per day in man. It contains two fully formed enzymes, pancreatic diastase (hydrolyzes starches), lipase (hydrolyzes fats), and the forerunner (trypsinogen) of a proteolytic enzyme (trypsin). The rate and character of the secretions have been shown to vary with the character of the food. The maximum is reached between the beginning of the second and the end of the fourth hour after the ingestion of the meal.

The mechanism by which pancreatic secretion is brought about is as follows: When the food mixed with acid gastric juice escapes from the stomach, the acid is absorbed by the mucous membrane of the duodenum; in

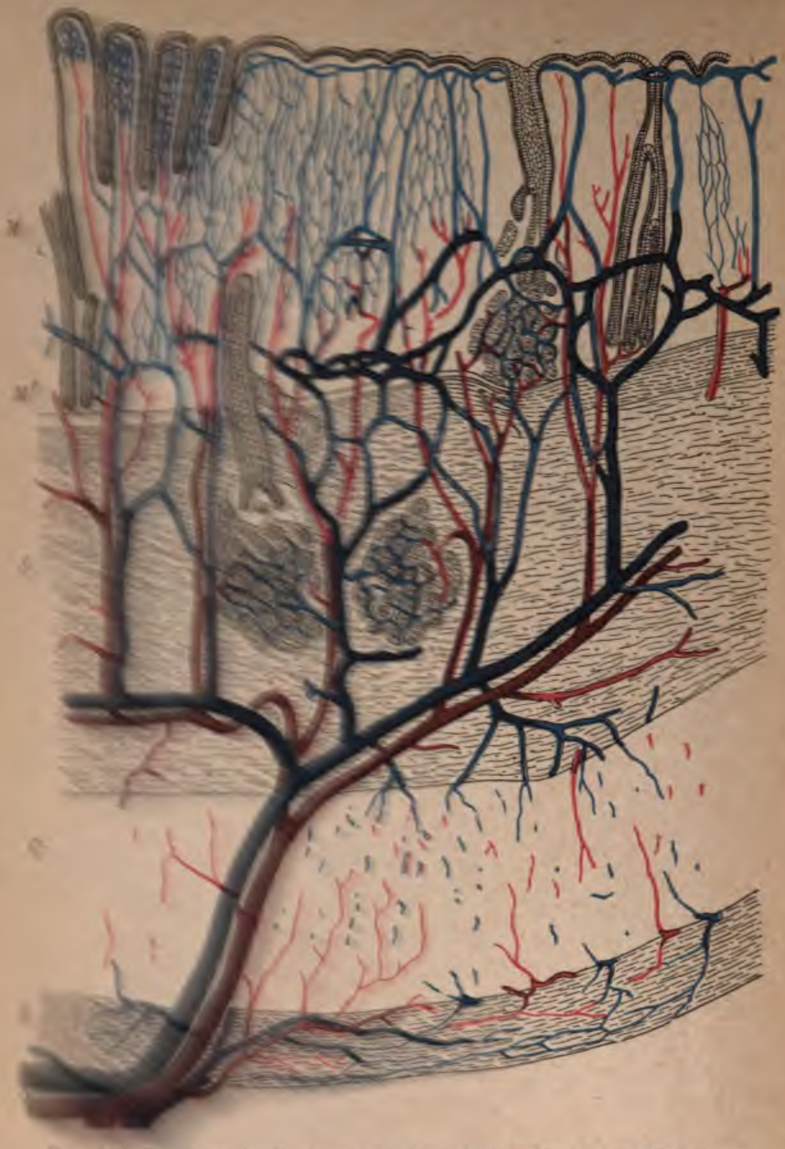


Fig. 141 B. — Longitudinal section through the pyloric ring of the stomach. On the left of the figure is the intestine and on the right the stomach. Arteries in red; veins in blue. *M*, mucosa; *M'*, thin muscular layer (muscularis mucosæ); *S*, submucosa (composed largely of connective tissue); *C*, circular muscle coat; *L*, longitudinal muscle coat. Note carefully the distribution of the blood vessels. (Mall.)

its passage through the intestinal wall on its way to the blood stream, the acid unites with a substance (prosecretin) contained in the cells of the membrane, with which

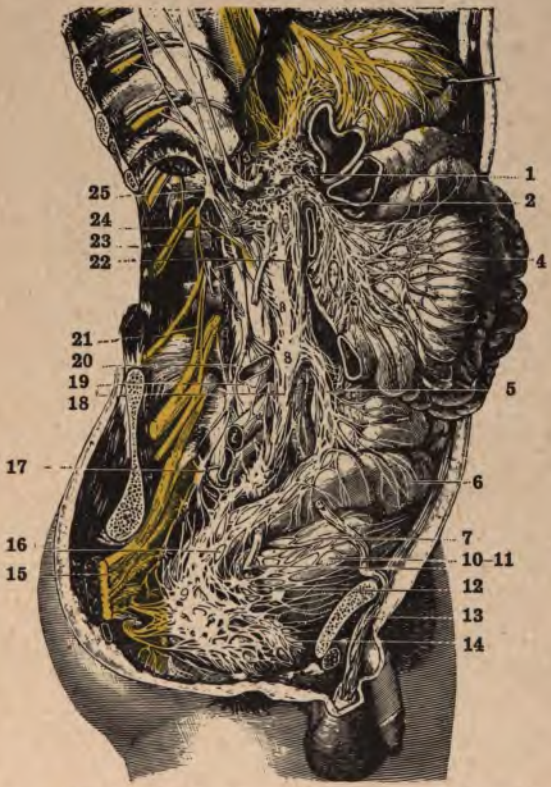


FIG. 143. — The abdominal viscera with splanchnic and somatic plexuses. 1, cœliac plexus; 2, portion of the mesentery; 3, cœliac ganglion; 4, small intestine; 5, autonomic fibers passing to the large intestine; 6, large intestine; 7, deferent duct; 8, aortic plexus; 9, pelvic plexus; 10, bladder; 11, severed ureter; 12, seminal vesicles; 13, plexus surrounding the spermatic cord; 14, prostatic plexus; 15, sacral plexus, showing the origin of the sciatic and other somatic nerve trunks; 16, rectum; 17, sacral vertebral ganglia; 18, branches from the aortic to the hypogastric plexus; 19, severed inferior vena cava; 20, lumbar autonomic stationary ganglia; 21, lumbar plexus; 22, aorta; 23, nerve supplying the body wall; 24, severed renal artery; 25, first lumbar sympathetic ganglion; *i*, right iliac artery. (Testut, after Hirschfeld.)

it forms a substance known as secretin. This substa on being carried by the blood stream to the pancr stimulates chemically the gland to secretory activi Thus secretin coördinates the activity of the stoma with that of the pancreas and this coördination thou slower is as perfect as those which are brought about nervous reflexes. Here, instead of the nerve impulse have a chemical substance and instead of the nerv path we have the circulatory system. Chemical su stances which act in this way are known as hormones (p. 35). The pancreas is supplied with secretory fib from the vagus and sympathetic system, but their acti is apparently only of secondary importance to that secretin.

Trypsin. — The formation of the active enzyme tryp from its inactive forerunner trypsinogen takes pl through the action of a kinase (enterokinase) which produced by the intestinal mucosa. When enterokin and trypsinogen are brought together the resulting s stance is trypsin, a powerful proteolytic enzyme (Fig. 1

The action of trypsin differs from that of pepsi several particulars. Though it may act upon prote slightly acid media, it may also act in a neutral or str alkaline solution, and secondly the decomposition o proteins is carried much further than it is with p the end products being known as amino bodies.

Diastase. — The action of the pancreatic di precisely similar to that of ptyalin (also kno diastase). It attacks starch, with products of hydrolytic split maltose.

Lipase. — When a globules which suspension in

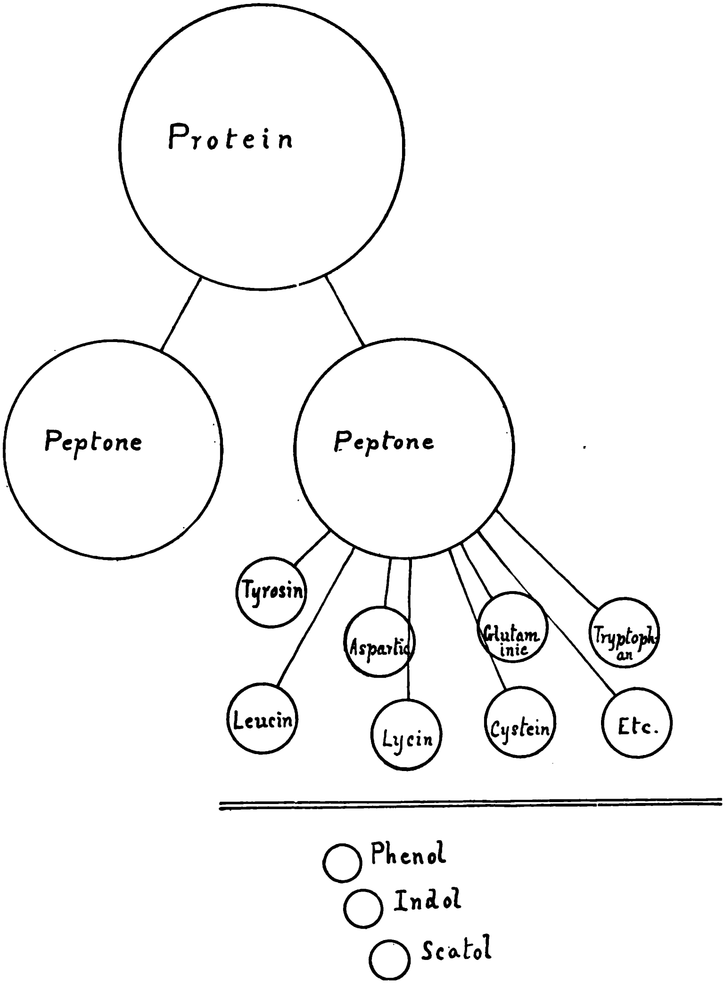


FIG. 144. — Diagram illustrating the digestion of proteins by pepsin and trypsin. The first series of reductions of the size of the molecules results in the formation of the soluble and absorbable peptone; the second series, in the formation of various amino bodies (tyrosin, leucin, etc.), of which the more important are mentioned in the diagram. With the formation of amino bodies digestion stops. Putrefaction of the intestinal contents, however, leads to the formation of other substances, phenol, indol, scatol, which are therefore separated by a double line from the amino bodies.

emulsified. This condition may be brought about by a prolonged shaking of the oil in a viscous solution of soap. In the intestine emulsification of fat occurs through the action of lipase. The lipase causes a hydrolytic splitting of some of the fat into glycerine and fatty acid. This acid combines with the alkali which is always present in the intestine to form soaps. These soaps emulsify the remaining fats, which because of their finely divided state, are then more quickly split by the lipase. The nature of action of lipase is made clear in the accompanying table showing the digestion of fats.

Digestion of Fats

1. A simple chemical reaction, an acid and a base forming a salt and water, thus base + acid = salt + water.

Caustic soda + nitric acid = sodium nitrate + water

$$(Na)OH + (NO_3)H = NaNO_3 + H_2O$$

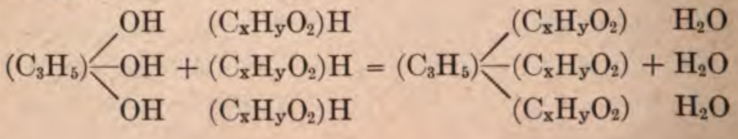
2. Formation of soap, a reaction similar to the preceding.

Caustic soda + fatty acid = soap + water

$$(Na)OH + (C_xH_yO_2)H = Na(C_xH_yO_2) + H_2O$$

3. Formation of fat, a reaction similar to the preceding.

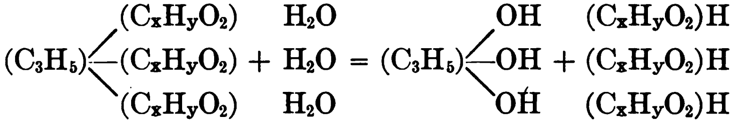
Glycerin + fatty acid = fat +water



$$(C_3H_5)\begin{cases}OH\\OH\\OH\end{cases} + \begin{array}{l}(C_xH_yO_2)H\\(C_xH_yO_2)H\\(C_xH_yO_2)H\end{array} = (C_3H_5)\begin{cases}(C_xH_yO_2)\\(C_xH_yO_2)\\(C_xH_yO_2)\end{cases} + \begin{array}{l}H_2O\\H_2O\\H_2O\end{array}$$

4. Digestion of fats, a reaction which is exactly the reverse of the preceding.

Fat + water = glycerin + fatty acid



$$(C_3H_5)\begin{cases}(C_xH_yO_2)\\(C_xH_yO_2)\\(C_xH_yO_2)\end{cases} + \begin{array}{c}H_2O\\H_2O\\H_2O\end{array} = (C_3H_5)\begin{cases}OH\\OH\\OH\end{cases} + \begin{array}{c}(C_xH_yO_2)H\\(C_xH_yO_2)H\\(C_xH_yO_2)H\end{array}$$

The action of the lipase is greatly accelerated by the presence of bile, a fact which has been expressed by saying that bile is a " co-ferment."

Intestinal Secretions and Enzymes. — The small intestine is lined with tubular glands which secrete an intestinal juice (succus entericus). This secretion has little importance in digestion. The intestinal mucosa, however, contains several important enzymes.

1. Enterokinase and prosecretin have already been mentioned. The former acts with trypsin to form trypsinogen; the latter combines with acid to form secretin.

2. Erepsin, an enzyme which splits peptones, with the formation of amino bodies.

3. Sugar-splitting enzymes which cause the hydrolytic splitting of more complex sugars into simpler ones. Thus maltose and cane sugar are not absorbed as such but must be further hydrolyzed by the enzymes of the intestines to such simple forms as dextrose (often called glucose).

Absorption in the Small Intestine. — Absorption takes place very readily in the small intestine. The carbohydrate food is absorbed as simple sugars, chiefly as dextrose. These sugars enter the portal vein and pass to the liver. In this organ the excess of sugar is withdrawn and stored as glycogen, so that the amount of sugar in the general circulation is kept quite constant, about 0.1 per cent. The liver, however, has limits to its activity in this respect, so that when very large quantities of carbohydrates are eaten the amount of sugar in the blood is increased and sugar begins to appear in the urine (alimentary glycosuria). The amount of any carbohydrate that may be eaten without causing alimentary glycosuria is designated as the "assimilation limit" of that carbohydrate. The assimilation limit of starch is higher than that of sugar, for the digestion and absorption of the former are slower and hence the liver does not so easily become embarrassed by a sudden inrush of absorbed sugar when starches are eaten.

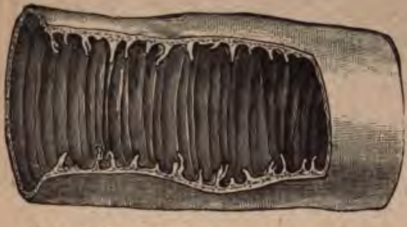


FIG. 145. — Plicæ circulares. Portion of the small intestine laid open. (Brinton.)

The carbohydrates which are not absorbed undergo a decomposition in the intestine owing to bacterial action, with the formation of acetic, lactic, and other acids. The decomposition is of normal occurrence, but when it is increased by a deficient absorption or an excessive amount of carbohydrate, the

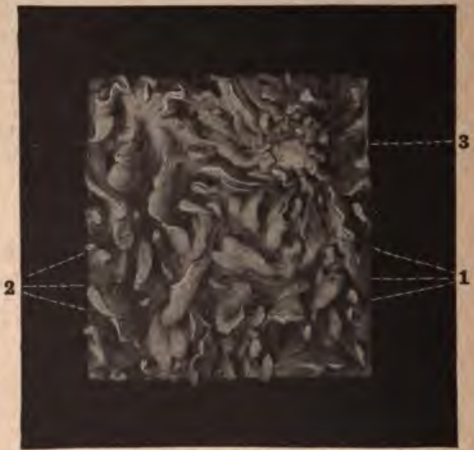


FIG. 146. — Surface view of small intestine showing villi (1) with crypts between (2) and a "solitary lymph nodule" (3). (Spalteholtz.)

acids may become irritating to the small intestine and lead to diarrhœa and other intestinal disturbances. Fats are absorbed as glycerine and fatty acid, which are again recombined in the cell. The fat droplets then enter the lacteals, are collected into the thoracic duct and finally discharged into the left subclavian vein. Some of the fat passes directly into the blood vessels of the villi. Some fats are much more readily absorbed than others, as shown by the following figures: — olive oil is absorbed to the extent of 97.7 per cent, goose and pork fat 97.5 per cent, mutton fat 90 to 92.5 per cent, spermaceti 15 per cent.

Proteins are absorbed into the blood probably as amino bodies and other very simple products of the hydrolytic cleavage of proteins.

By the time the food reaches the end of the small intestine most of its protein has been absorbed. The completeness of the absorption varies with the character of the protein. Milk, eggs, and meat are readily absorbed,

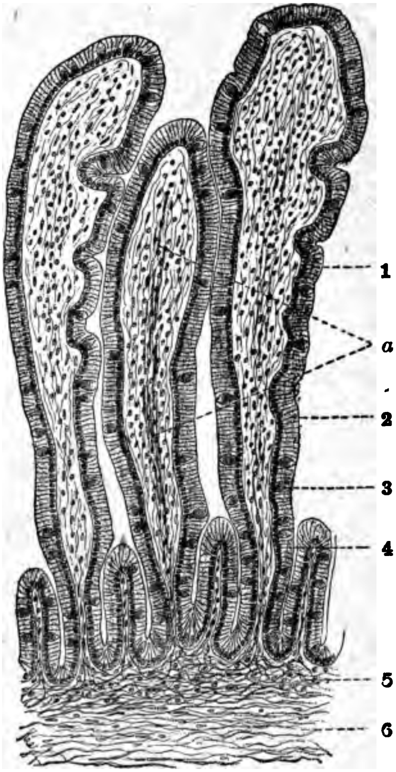


FIG. 147. — Crypts and villi of the small intestine; section. At *a* is a collapsed chyle vessel in the axis of the villus. 1, epithelium of the villus; 2, epithelium of the villus; 3, goblet cell; 4, gland (crypt) of Lieberkuehn; 5, mucosa; 6, muscularis mucosæ. (Boehm and Davidoff.)

97 to 99 per cent, vegetable proteins less completely, 70 to 83 per cent, owing to their admixture with indigestible cellulose.

In this region the conditions for absorption are very favorable on account of the enormous surface presented by the intestinal mucosa. This extension is accomplished in several ways (1) by the length of the small intestine which is 6 m. long, (2) by the ridges or circular folds which run cross-wise on the mucosa (Fig. 145), and (3) by finger-like prolongations (villi, Figs. 146, 147, and 148) which give the mucosa a velvety appearance.

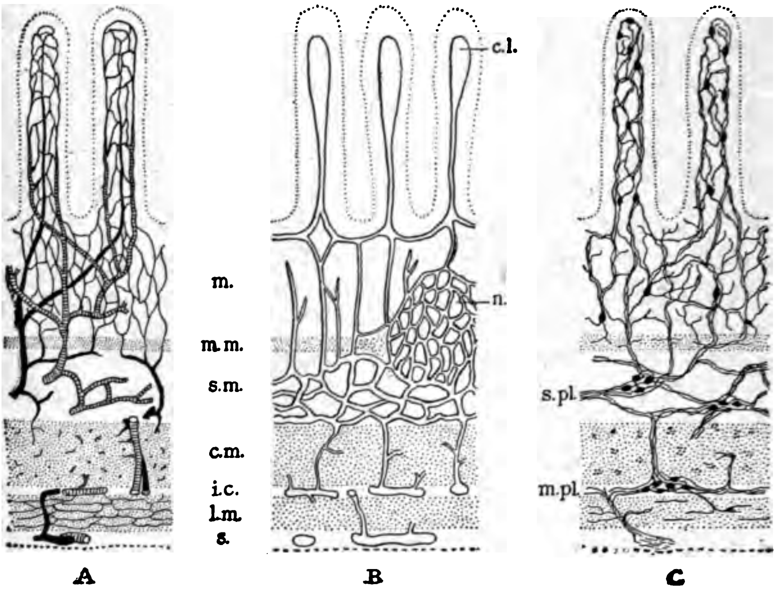


FIG. 148. — Diagram of the intestinal villi. *A*, diagram of the blood vessels of the small intestine; the arteries appear as coarse black lines, the capillaries as fine ones, and the veins are shaded (Mall). *B*, diagram of the lymphatic vessels. (Mall.) *C*, diagram of the nerves. (Cajal.) The layers of the intestine are: *m*, mucosa; *m.m*, muscularis mucosæ; *s.m*, submucosa; *c.m*, circular muscle layer; *i.c*, intermuscular connective tissue; *l.m*, longitudinal muscle; *s*, serosa or peritoneal membrane; *c.l*, central lymphatic; *n*, nodule; *s.pl*, submucous plexus; *m.pl*, myenteric plexus.

Digestion and Absorption in Large Intestine. — The digestion which occurs in the large intestine is due not to the local secretions but to the presence of enzymes brought down from the small intestine in the food. Absorption continues as in the small intestine. Carbohydrate decomposition leads as we have seen to acid formation in the small intestine. The acidity, weak as it is, together with the rapid absorption of the protein, prevents its decomposition under normal circumstances.

In the large intestine decomposition of protein is of normal occurrence. When this is excessive the products of putrefaction may be absorbed in such quantity as to disturb the health. Among the products of decomposition of protein in the large intestine are carbolic acid, indol, and skatol; after absorption these substances are in a somewhat altered form excreted in the urine. Their presence in the urine is taken to indicate that the amount of putrefaction occurring in the intestine is excessive.

CHAPTER XI

LIVER, SPLEEN, AND EXCRETORY ORGANS

The Liver

THE liver receives blood from two sources. By the hepatic artery blood is brought to the liver from the aorta and by the portal vein from the capillaries of the stomach and intestine. Both vein and artery break up into capillaries in the liver, which unite again to form the hepatic vein which empties into the inferior vena cava.

The liver possesses four distinct functions:

Secretion of Bile. — In the first place the liver is a gland, the secretion of which is known as bile. The bile is in part useful and in part purely waste. In man the amount of bile secreted in one day ranges between 500 and 800 cc.

The important ingredients are water, pigments, and bile salts. When the red blood corpuscles disintegrate the hemoglobin is brought to the liver. Here the iron is split off and retained in the body while the rest of the hemoglobin molecule is excreted and gives to the bile its high color.

It is the bile salts which act as a co-ferment for the lipase. As already stated the fats are digested much more completely when bile is present in the intestine. The bile salts also aid in the emulsification of the fats, thereby facilitating still further the action of the lipase. This aid which the bile gives to the digestion of fats has led to the belief that the secretion has antiseptic properties.

This is probably not the case; the disturbances associated with the deficiency of the bile are due to the presence of undigested fat in the intestine which coats the rest of the food, hinders its digestion and thus gives rise to the untoward symptoms. The secretion of bile appears not to be directly under the control of the nervous system. Increase in the activity of the organ may be brought about through vasomotor inhibition and consequent vascular dilatation in the organ. It may also be caused by the circulation in the blood of certain substances, *e.g.* secretin and the bile salts, which are accordingly designated chologogues. Although continuously secreted, the bile finds its way into the intestine only at appropriate intervals. Each gush of chyme into the intestine is accompanied by a contraction of the gall bladder and an inhibition of the sphincter of the gall duct. The mode of action is uncertain, but as both afferent and efferent excitatory and inhibitory fibers from the gall bladder have been demonstrated the action may be a reflex. On occlusion of the bile duct, the bile finds its way into the blood stream, either directly or through the lymphatics, and gives rise to the yellow pigmentation (jaundice) of the skin and conjunctiva.

Liver and Carbohydrates. — The second function of the liver is concerned with the metabolism of carbohydrates. We have seen that the carbohydrates are digested and pass into the portal circulation in the form of glucose. This glucose passes from one part of the body to the other and it is probable that it is in this form that it is used for heat ~~and~~ energy. The amount of glucose in the blood is very small and as the demand for glucose may be both considerable and sudden, a considerable amount of carbohydrate is kept on hand — stored in the body. The carbohydrate is not, however, stored as glucose. For purposes of storage the glucose, doubtless in the presence of the special " glycogenic " enzyme, gives up water and undergoes molecular rearrangement, the result being the formation of a substance — glycogen — which closely resembles starch. It is as glycogen that carbohydrates are stored in the animal body just as in the plant kingdom they are stored as starch. When the amount of sugar in the blood falls too low some of the glycogen takes up water and splits to form glucose again, which passes into the circulation. In this manner the supply of sugar in the blood is kept constant. The liver is the chief storehouse of glycogen, the storehouse next in importance being the muscles. The glycogen in the liver may amount to 10 per cent of the weight of the organ but ordinarily it is not more than 1.5 to 4 per cent. In the muscles it may amount to from 0.5 to 0.9 per cent and the total amount in the muscles is about equal to the amount in the liver.

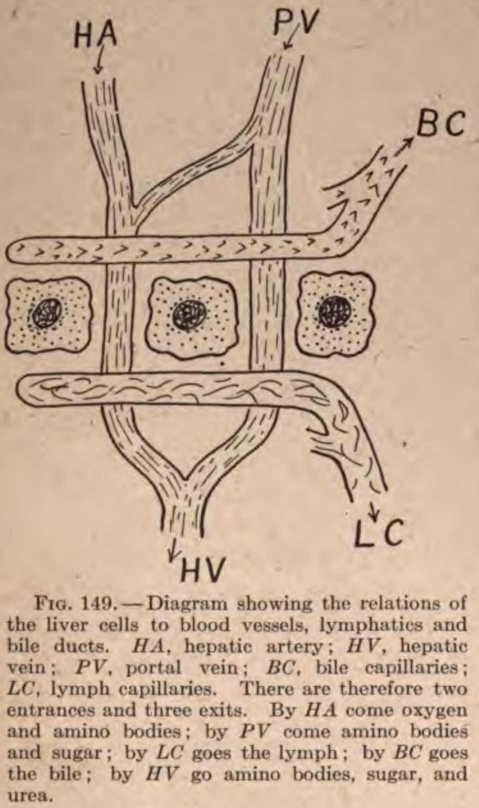


FIG. 149. — Diagram showing the relations of the liver cells to blood vessels, lymphatics and bile ducts. *HA*, hepatic artery; *HV*, hepatic vein; *PV*, portal vein; *BC*, bile capillaries; *LC*, lymph capillaries. There are therefore two entrances and three exits. By *HA* come oxygen and amino bodies; by *PV* come amino bodies and sugar; by *LC* goes the lymph; by *BC* goes the bile; by *HV* go amino bodies, sugar, and urea.

The position of the liver in relation to the portal circulation is of great importance since it is thereby enabled to waylay the glucose on its way from the intestine to the systemic circulation and to abstract and retain as glycogen the major part of it.

The third function of the liver is the formation of fibrinogen. The process is an obscure one but it has been conclusively shown that the presence of the liver is necessary for the formation of this substance.

Lastly, the liver forms urea, a relatively innocuous substance out of the poisonous products of protein metabolism—salts of ammonia and amino bodies (Fig. 149).

The Spleen

Nothing is known positively in regard to the function of the spleen, but there is some evidence that it is this organ that filters off from the circulation the worn-out red blood corpuscles.

The Kidney

The place of the kidney among the organs of excretion may be understood from the following table:

PRODUCTS OF KATABOLISM	PLACE OF ELIMINATION
Water	Kidney, skin, lungs
Carbon dioxide	Lungs, skin, kidney
Sulphates, phosphates, etc.	Kidneys, skin
Nitrogenous waste	Kidneys, skin, intestine

The kidney is the principal organ for the elimination of nitrogen. The glomerular part of the kidney (Fig. 150) secretes the water and the salts, while the tubular part secretes the nitrogenous material.

Secretory nerves have not been demonstrated in the kidney. As in the case of the liver the activity of this organ depends upon the blood supply, *i.e.* upon the activity of the vasomotor nerves. The kidneys are very vascular organs and receive an exceptionally large proportion of the blood from the heart. The urine has a specific gravity of 1.020, is usually acid and contains water, inorganic salts, and bodies containing nitrogen such as urea, creatinin, and other substances. There is some evidence that the first of these is derived from the direct oxidation of amino bodies, and that the second is formed by the katabolism of tissue proteins.

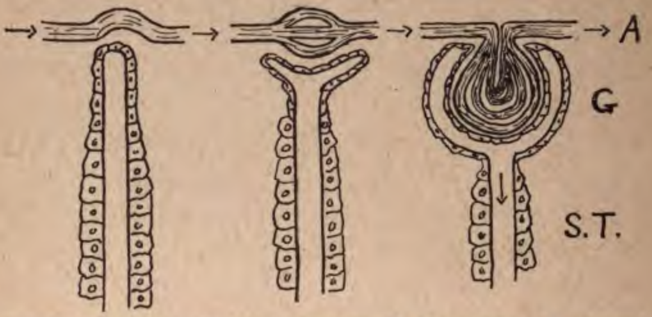


FIG. 150. — Diagram showing structure of glomerulus. *A*, artery; *G*, glomerulus; *S.T*, secreting tubule. The glomerulus is a device for securing a large capillary surface where elimination can take place. The tortuous course of the secreting tubules, which renders them immensely long, serves to increase the secreting surface of these structures. The complexity of the diagrams increases from left to right, that on the right representing a glomerulus in a schematic way.

The kidney cells secrete continuously and the urine is crowded down the tubules and accumulates in the basin (pelvis) of the kidney. From here it is passed down the ureters to the bladder by the peristaltic contractions of the ureters. These contractions begin at the pelvis of the kidney and pass down every ten to twenty seconds to the bladder, causing the urine to be expelled with a little spurt. This action is apparently independent of any nervous influence and is the property of the muscle tissue itself.

The bladder, a bag of plain muscle lined with epithelium, receives the urine, which is kept from leaking out through the urethra by the action of the internal sphincter and from backing up into the ureters by the fact that these passages enter the bladder at such an acute angle that the mucous membrane of the bladder acts as a valve.

As the pressure of the urine in the bladder increases the desire to micturate is felt. This may lead to micturition which is essentially a contraction of the muscles of the bladder accompanied by a relaxation of the sphincters. Or there may be a temporary prevention of the act through the tightening of the external sphincter. The desire to micturate depends not only upon the amount of urine in the bladder but also on the tonus of the bladder, in other words the state of contraction of the bladder musculature upon which depends the size of its cavity. The tonus of the bladder varies greatly as the results of reflex influences and hence the desire to micturate may come or go through purely nervous causes (Fig. 151).

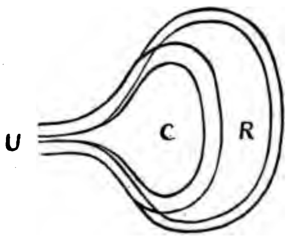


FIG. 151. — Diagram of bladder, showing the effect of a change of tonus upon the capacity of the viscus. *U*, urethra; *C*, contracted bladder (tonic); *R*, relaxed bladder (atonic).

This statement implies an extrinsic nerve supply and this has actually been shown to exist. Besides the afferent there are two sets of efferent nerves, such that stimulation of the one causes relaxation of the muscular walls and contraction of the internal sphincter, while stimulation of the other causes contraction of the walls and relaxation of the sphincter.

Secretion of Sweat

The sweat or perspiration is the secretion of the sweat glands. The amount secreted under normal circumstances is 700 to 900 grams per day. In composition it contains, besides water, NaCl, urea, and so forth.

The amount of urea is very small, but under certain circumstances, *e.g.* muscular work with profuse sweating, it may be considerably increased.

The glands are furnished with secretory fibers both excitatory and inhibitory which are reflexly stimulated principally by changes in temperature of the environment.

CHAPTER XII

INTERNAL SECRETION

THE term internal secretion is used to designate those secretions of glandular tissue which instead of being carried off to the exterior by a duct, are eliminated by the cells into the blood or lymph. The internal secretion of an organ often has a profound influence upon the activity of other organs and upon the body as a whole. In many cases, however, the normal function of the secretion is but little understood and it is only when the glands are diseased or removed that we perceive that their integrity is necessary for the normal carrying out of the body functions.

Liver. — As already stated, the liver forms and pours out into the blood two substances, sugar and urea. They are examples of physiologic activity which really belong in the category of internal secretions.

Suprarenal Bodies. — These bodies secrete a substance (adrenalin) which has the power of raising the blood pressure, of slowing the heart, and of increasing the amount of sugar in the blood stream. The rise in blood pressure is due to the constriction of the blood vessels especially in the splanchnic region. The gland is supplied with secretory fibers which may be stimulated reflexly. Sensory stimuli and strong emotions increase the activity of the gland. On the strength of these facts the interesting hypothesis has been advanced that the suprarenals are "emergency organs," that at times of great emotional stress, fear and the like, their secretion is increased, with the result of shunting the blood from the intestines into the neuromuscular mechanism and of increasing the amount of sugar available for muscular work.

Under conditions of rest the suprarenals exercise a considerable influence as seen by the effects of extirpation or destructive disease of the glands. Notable among these is great muscular weakness and marked loss of vascular tone.

Testes and Ovaries. — Both testes and ovaries possess a double function. In the first place that of forming the reproductive cells and in the second place that of furnishing to the blood an internal secretion which is necessary for the normal development of the sexual instincts and of the secondary sexual characters. Thus the removal of the testes in young males results in the absence of the changes in voice, growth of hair, and so forth and of sexual desire which normally occur at the time of puberty. If in addition to the removal of the testes ovaries have been grafted into this young male, the latter develops all the secondary sexual characters of the female. Naturally, the latter experiment has been performed only in the case of animals. In these it has resulted in the development of the feminine type as to size, character of the hair, development of the mammæ, and so forth, to the extent which causes the animal to be mistaken for a female by others of its own species.

Removal of the ovaries in women results in an artificial menopause, with degeneration of the uterus and often also distressing physical and mental symptoms. But these symptoms disappear and sexual desire returns when an ovary is grafted into the individual. Ovariotomy in young female animals results in failure of the uterus to develop.

Pancreas. — That the pancreas gives off an internal secretion is evident from the following facts: (1) its complete removal causes definite symptoms, (2) these symptoms disappear when pancreatic tissue is grafted beneath the skin, (3) ligation of the ducts of the pancreas has no influence on these phenomena. The symptoms which result from the removal of the pancreas are marked glycosuria, polyurea, abnormal hunger and thirst, emaciation, muscular weakness, and death in a few weeks. Of these symptoms glycosuria is regarded as most significant and the pancreas is credited with some important rôle in the metabolism of sugar.

Thyroid Gland. — The function of the thyroid gland is still largely a matter of conjecture. Its integrity is apparently necessary for continuance of normal metabolism. Degeneration of the gland brings about a condition known as myxœdema, while its congenital defect causes cretinism. Both these conditions are characterized by abnormalities in skin, hair, mentality, and so forth, which can, however, be relieved by feeding thyroid extract to the patient. On the other hand, the gland may function excessively (exophthalmic goiter) and produce quite different but hardly less distressing symptoms which can be removed only by excision of the gland.

Parathyroids. — The parathyroids appear to have the function of neutralizing some toxine formed in the body, for their excision leads to death with convulsions. For the physiologic action of the thymus, hypophysis, pineal body, the reader is referred to more extensive works.

CHAPTER XIII

METABOLISM

Nutritional Equilibrium. — When the amount of nitrogen which is contained in the food is equal to that which is contained in the excreta (chiefly in the feces and urine), it is evident that the body is neither storing nitrogen nor losing it. This condition is known as nitrogen equilibrium. During active growth of muscle, as, for example, during convalescence or in childhood, the nitrogen of the food goes to the formation of new protein tissue to the extent of 16 grams of nitrogen to each 100 grams of protein. Consequently an analysis of the food would show a greater amount of nitrogen than that contained in the excreta. On the other hand, in fasting the kidneys still continue to eliminate nitrogen although in reduced quantity so that the output in nitrogen is greater than the intake, which during fasting is nil.

In like manner the carbon intake and the carbon excreted (chiefly in the breath) may be determined and the presence or absence of carbon equilibrium be established. If the individual is losing or gaining fat, this equilibrium will be disturbed.

Equilibrium in respect to nitrogen and carbon may be maintained at various " levels " so to speak. That is, the amount of food eaten may be increased or diminished often to a considerable degree without disturbing the equilibrium. This means that the more the nitrogen ingested the greater the quantity which is excreted and the more the carbon that is ingested the greater the quantity which is excreted. It is a matter of common experience that some people do not readily lay on fat. The more they eat the more they oxidize, and the output remains equal to the intake no matter how much the latter is increased.

If nitrogen equilibrium can be established at various levels the question in practical dietetics which arises is: At what level should it be maintained to secure the best results? Unfortunately, this question cannot be answered with certainty. All that can be said is that (1) the amount usually taken by mankind the world over is 100 to 120 grams of protein a day; (2) experiments have shown that for considerable periods at least the body can be maintained on 30 to 50 grams of protein a day; (3) moreover, the Bengalis consume habitually only about 37 grams daily, and in those persons who are on a milk diet the intake of protein is very low. But whether one is better or worse off for a low protein diet is uncertain and our present knowledge of the matter does not warrant any conclusion as to the optimum amount of protein to be ingested.

The result of protein digestion is, as we have seen, that the amino bodies in the circulating blood are increased in amount. The fate of these bodies varies. They may be taken up by the tissues, combined to form proteins used to repair the wasting tissues. Secondly, the amino bodies may split at once into a nitrogenous part and a non-nitrogenous part. The former passes to the liver, is there transformed into urea to be excreted subsequently by the kidney. The latter is used in the formation of fat or sugar and is sooner or later oxidized with the liberation of energy and the formation of CO_2 and H_2O.

Adequate Proteins. — Different proteins have very different nutritive values, depending upon the particular amino bodies of which they are composed. We cannot make tissue protein unless we are provided with all the amino bodies which go to make it up, namely: tyrosin, leucin, aspartic acid, glutaminic acid, tryptophan, lycin, cystein, etc., etc.

Food proteins which contain all these groups can be used as tissue builders but those which do not can only be used as sources of energy and their value is similar to that of the fats and carbohydrates. For example, gelatin lacks the groups tryptophan, tyrosin, and cystein and cannot therefore be used to repair the wear and tear upon the tissues. It is, however, a very valuable source of energy.

On the other hand, the casein of milk and the glutenin of wheat contain all the groups mentioned above and can therefore not only furnish energy but can build tissue. They are " complete " or " adequate " proteins and will sustain life.

Protein Sparing. — If an individual be brought into nitrogen equilibrium on as low a protein diet as possible and if then incomplete proteins (as gelatin), carbohydrates or fats be added to this diet it will be found that the amount of protein may now be considerably reduced without upsetting the nitrogen equilibrium. This fact is expressed by saying that the carbohydrates and fats are " protein sparers." As already stated, the food ingested fulfills two functions: (1) it is used in rebuilding waste tissues, (2) it is burned for the energy which it contains. If only protein be taken it must fulfill both functions but if carbohydrates and fats are included in the diet only as much protein is necessary as will suffice for the rebuilding [illegible] wasted tissues.

Carbohydrates. — The carbohydrates taken into the body have the following fate: They are absorbed as glucose and pass to the liver; there they are converted into glycogen (glycogenesis) and stored. As the glucose in the blood is used up it is replaced by the activity of the liver, which breaks down the glycogen (glycogenolysis) into glucose, which passes into the blood stream.

The glucose in the blood stream may be taken up by the muscles and stored as glycogen until needed or it may be utilized at once, being broken down into CO_2 and H_2O with the production of heat and work. Finally, as CO_2 and H_2O, the carbohydrates are eliminated from the body. When carbohydrates are not fed, the sugar in the blood can be kept up by the transformation of certain amino acids derived from protein digestion.

The amount of sugar present in the blood is small (0.1 — 0.15) and remarkably constant. This nice balance may, however, be disturbed in various ways. (1) If large quantities of carbohydrates be eaten the liver is inadequate to meet the demand upon its glycogenic power and an undue amount of sugar passes into the blood (hyperglycemia) and the surplus is promptly eliminated in the urine (glycosuria). (2) A hypersecretion of adrenalin, as already stated, causes an acceleration of the glycogenolytic process which results in hyperglycemia and glycosuria. (3) A decrease in the internal secretion of the pancreas causes a failure of the tissues to utilize sugar (glycolytic power), and the sugar which can no longer be oxidized as under normal conditions, accumulates in the blood (hyperglycemia). The surplus is secreted by the kidney (glycosurea). (4) Lastly, certain drugs (as phlorrhizin) cause the kidney to let through the sugar which is normally present in the blood (glycosurea) so that the body is drained of its normal sugar supply. The carbohydrates have a fourfold function. They furnish (1) energy for muscle work, (2) they furnish energy for heat, (3) they are "protein sparers," and lastly (4) they may be converted into body fat.

Fats. — After passing into the lacteals and thence into the blood the fat droplets circulate for a while until gradually picked out and utilized by such tissues as require them. There they are oxidized with the liberation of energy. The excess is stored in the tissue as body fat. The fat of the body may be derived from all three classes of foodstuffs — proteins, carbohydrates, and fats. The difference in the ease with which different persons lay on fat depends upon the difficulty which people experience in oxidizing their food. Obesity is due to deficient power of oxidation. This deficiency may be hereditary or it may be due to sedentary life or to alcoholic beverages. The uses of fat are (1) to provide a store of reserve foodstuff, (2) to furnish heat, (3) to act as a protein sparer.

Salts. — The inorganic salts are of no value as contributors of energy but they are quite indispensable to life. Their uses are various. Calcium, for example, is necessary for the formation of bones and for the clotting of the blood. From sodium chloride (NaCl) comes the hydrochloric acid (HCl) of the gastric juice. Iron is a necessary constituent of the hemoglobin. The relation of the salts of the blood to the rhythmic action of the heart has already been referred to. They are also essential for maintaining the proper osmotic relations. (See page 191.)

"Vitamines." — Certain substances, the chemical nature of which is at present unknown, seem to be necessary for the maintenance of health. For when the diet does not contain these substances various diseases are induced, such as scurvy and beriberi. Extensive experiments upon the effect of diet upon rats have shown that there are at least two substances necessary for the normal growth and vitality of these animals. One or both of these substances are present in various sorts of food (butter fat, alfalfa leaves, wheat germ, corn, millet seed, and so forth) and the diet selected must always be such as to include both of them. This line of research is of immense importance to Dietetics, but its physiological significance will be disclosed only when the chemical nature of these "vitamines," as they have been called, has been determined.

Energy of the Food. — All the energy required in muscular work is derived from the carbohydrates and fats unless these foodstuffs are not supplied in sufficient abundance. In the latter case, since the energy must be derived from some source, protein is used. Thus with an abundant nonprotein diet the nitrogenous wastes are not increased during exercise, nor are they decreased during sleep.

As long as the temperature of the body remains constant the increase or decrease in heat production which is the reaction to changes in outside temperature is derived from the nonprotein food. It is customary to measure heat in calories. A large calorie (Cal.) is the amount of heat required to raise one kilogram of water 1° C. and a small calorie (cal.) is the amount required to raise a gram of water 1° C. The amount of chemical energy in any substance determines its " heat value." This may be ascertained by burning the substances and noting the amount of heat given off. One gram of sugar, for example, on being burned to carbon dioxide and water, gives off 4.1 Cal. of heat. Whether this burning or oxidation occurs in a test-tube or in a living being is immaterial as far as the amount of energy produced is concerned. In the case of the living organism, the energy may appear in several forms, as heat, mechanical work, and so forth, but in any case it is always equivalent to 4.1 Cal. and, if it all appeared as heat, it would be 4.1 Cal. The amount of energy generated normally by a human being is 2400 Cal. per day. (2,400,000 cal.) Compare with this the following:

1 gram protein yields	4.1 Cal.
1 gram carbohydrate yields	4.1 Cal.
1 gram fat yields	9.3 Cal.

From this it is evident that whatever be the proportion of proteins, fats, and carbohydrates in the diet, the total energy value must add up to 2400 Cal. if the body is to remain in equilibrium. Of course if the man is in bed less will be required than if he were doing severe muscular work. This is shown by the following figures:

Number of Calories per hour, sleeping	71
Number of Calories per hour, sitting	97
Number of Calories per hour, standing	114
Number of Calories per hour, severe muscular work	653

CHAPTER XIV

HEAT REGULATION

In frogs, fish, insects, and many other animals the temperature of the body varies with that of the surrounding medium. Its chemical processes keep it a little warmer than the medium (air or water) in which it lives, but as the medium becomes hotter or colder the temperature of the organism experiences a corresponding rise or fall. In birds and mammals, however, the temperature of the body varies but little. Indeed it remains practically constant in spite of changes in the surrounding medium which are often very great as between winter and summer or very sudden as when a seal which has been basking on the warm rocks takes a plunge into ice water.

Naturally the temperature of the body depends upon the relation of the production of heat to the loss of heat. If, therefore, the temperature of the body is to remain constant there must be some mechanism or mechanisms for regulating the production or loss of heat or both these processes.

Regulation of Heat Production. — The production of heat in the body is due to the oxidation of foodstuffs. Just as coal burned in the engine gives off heat so do the foodstuffs give off heat when oxidized. If the body is in equilibrium — neither losing or gaining weight — the amount of heat produced varies with the amount and character of the food ingested. The heat value or calorific value of the various food stuffs has already been referred to. This form of regulation is, however, ill adapted to meeting the demands of sudden changes, but there is a second mode of increasing heat production which is more rapid in that it draws at once upon the supply of glycogen already present in the body. Of course, this glycogen must be sooner or later replaced through the ingestion of more food, but it serves to supply the immediate demands of the organism for more fuel.

The mode to which reference is being made is that of muscle activity during which glycogen is broken down with the liberation of energy of motion and also with the liberation of heat. This muscular activity may be either voluntary or reflex. In the former case we stamp about, thresh our bodies with our extended arms, take a brisk walk, or run. In the second case there is a reflex increase in the tonus of the muscles. This subdued or continuous contraction is accompanied by a considerable increase in the amount of heat given off. If then, the reflex contraction becomes rhythmic (clonic) instead of constant (tonic) we have the phenomenon of the rapidly repeated small contraction which we call shivering. It is obvious, therefore, that the conscious effort to control our muscles so as to suppress shivering is unreasonable. It makes us warmer to shiver and the only rational way to stop shivering is to render it unnecessary by reducing the loss of heat from our bodies or by substituting for this involuntary muscle activity an activity which is intelligently directed and therefore more adequate to meet the demand for increased heat production.

It should be observed in passing that both physical [illegible] and external cold increase the appetite and conse[illegible] insure an increase in the intake of food to offset the increased consumption of glycogen. Furthermore, this afferent path of the shiver reflex is through the nerves which mediate cold sensation just as that of the sweating reflex is through the nerves which mediate the sensation of heat.

Regulation of Heat Loss. — The loss of heat from the body takes place in four different ways: (1) through the excreta, (2) in the expired air, (3) through evaporation of the sweat, and (4) by conduction and radiation.

The relative importance, under ordinary conditions, of these four avenues of heat loss is as follows:

(1)	1.8% or	48 Cal.	in feces and urine.
(2)	3.5% or	84 Cal.	in warming the air.
	7.2% or	182 Cal.	in vaporizing the water.
(3)	14.5% or	364 Cal.	evaporation from the skin.
(4)	73.0% or	1792 Cal.	conduction and radiation from the skin.
	100%	2470 Cal.	

Of these the first can be affected voluntarily to only a limited extent, as by the ingestion of cold water which results in the increase in elimination of warm urine and consequently in the loss of heat to the body.

The second is subject in man to but small variations. It is true that as the result of heat alone the respirations are quickened but this increase is not very significant as a mode of heat regulation. During exercise, however, the respirations are enormously increased both in rate and depth and even in man play an appreciable rôle in the regulation of body temperature. It is interesting to observe that in animals which do not sweat, this method is very important, even while resting, as in dogs who cool themselves in warm weather by panting.

The third mode of heat loss is that of **evaporation** of the sweat which in passing from the liquid state to that of vapor absorbs heat from the surrounding regions (air and skin) and consequently exercises a cooling influence. Whatever the demands of æsthetics there is no physiological justification in *wiping* off the sweat while fanning in that it hastens vaporization, cools the skin, and consequently is a rational procedure.

When sweat is not visible as drops upon the surface of the skin there is still going on (like the evaporation from the apparently dry leaves of plants) a so-called "insensible perspiration." The sweat glands may therefore be said to possess a tonic activity which when it becomes excessive constitutes the phenomenon of visible sweating. (See page 238.)

Lastly, conduction and radiation are to be considered. Naturally, the thicker the layer through which the heat of the body must pass the slower the conduction of heat from the body. The thickness of this layer can be modified in two ways, one being physiological, the other artificial. If the blood vessels of the skin are constricted then the distance through which the heat must travel (from the deeper blood vessels to the surface) is great and the loss of heat is slow. If, on the other hand, the blood vessels of the skin are dilated then the distance through which the heat must pass (from the superficial vessels to the surface of the body) is decreased and the rate of heat loss is correspondingly increased.

The amount of heat lost is, therefore, partly under nervous control. In warm weather the stimulation of the heat nerves of the skin causes reflexly a dilatation of the blood vessels of the skin and consequently the increase in the loss of heat already referred to. In cold weather the opposite condition is present.

The artificial method of controlling the loss of heat from the surface of the body is by varying the amount and character of the clothing. Since air is one of the poorest conductors of heat the warmest clothing is that which contains air immeshed in its fibers.

CHAPTER XV

REPRODUCTION

Introduction.—In the case of the amœba the process of reproduction is, as we have seen, the simplest imaginable. The animal merely elongates and divides into two parts, each containing approximately one half of the original cytoplasm and nuclear material, and each becomes at once in itself a complete individual. In the case of organisms which stand only a little higher in the scale than the amœba the process is somewhat more complicated. Here the division is preceded by fusion. One cell approaches another and the two fuse. The product of this fusion then divides in the manner of the amœba, and this process of simple division continues for several generations. Sooner or later, however, fusion again takes place, after which the division continues again for several generations more. It would appear that the union of one cell with another must occur periodically if multiplication is to continue indefinitely, and that if such a union does not take place, the organisms will finally become extinct. This process of union is known as fertilization.

In multicellular forms the union occurs between certain specialized cells. The latter are of two sorts, an active sort (pollen, spermatozoa) and a passive sort (ova), and the union in question occurs only between two reproductive cells of different sorts. In some species both sorts of cells occur in the same individuals, but in other species each individual contains but a single sort of reproductive cell, and the individuals of such a species may therefore be divided into two classes (male and female), depending on which sort of reproductive cells they contain.

It follows that in these higher forms the process of fertilization depends upon bringing together the male and female reproductive cells so that fusion may occur.

The modes in which this is accomplished are innumerable. In very simple types, as the sea urchin or starfish, the reproductive cells are passed out into the sea water, and these meeting together, fertilization occurs.

In the higher animals, as the frogs, the male accompanies the female during the breeding season, so that the meeting of the reproductive cells in the water is facilitated by the nearness of the two sources from which these cells are derived.

In birds and mammals, including human beings, a mechanism exists whereby fertilization is made to occur within the body of the female.

Testes and Spermatozoa. — Let us now consider more in detail the form of reproduction which occurs in human beings. In the human male the reproductive cells are formed in the testes. These organs consist of two distinct parts, that in which the spermatozoa are formed by the continuous division of the specialized reproductive cells, and the parts which lie between these cell groups, the "interstitial" parts, containing the interstitial cells. This interstitial tissue has been called the "pubertal gland." Its internal secretion is apparently necessary for the appearance of puberty in the male. This condition is marked by a change in the voice, growth of hair, and development of ripe spermatozoa. In the male sexual maturity and puberty are attained at the age of about fifteen and the reproductive power lasts indefinitely.

The spermatozoa (Fig. 152) which are thus developed under the influence of the pubertal gland are small cells ending in a single cilium, by means of which the cells propel themselves with a wriggling motion which is always directed against the current, if there is a current, in the liquid in which the spermatozoa find themselves.

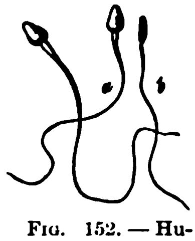


FIG. 152. — Human spermatozoa. *a*, view of the broad surface; *b*, in profile. (H. Frey.)

Fertilization. — After their formation the spermatozoa pass down the deferent duct (see Fig. 153) to the seminal vesicles, where they accumulate. The process by which the spermatozoa are transferred to the body of the female (coitus) consists of two reflex acts. The first (erection) is a psychical reflex similar in its general character to the psychical secretion of saliva (see p. 213); the second (ejaculation) is ordinarily a subcortical reflex similar in its general character to the reflex ejaculation of bile into the intestine (see p. 233).

These most important reflexes for the life of the species take place in the following way: the female stimulates the male through the organs of special sense (sight, hearing, etc.). The stimuli pass to the cortex, where under favorable conditions they arouse a state of consciousness known as sexual desire. If this sex hunger be present, the impulse then passes from the cortex down the cord and out from the lumbar region of the cord by the vasodilator nerves of the penis. As the result of this an enormous dilatation of the penis occurs so that it becomes turgid and rigid and may now be thrust into the vagina of the female. The mechanical stimulation of the friction of the penis against the walls of the vagina then

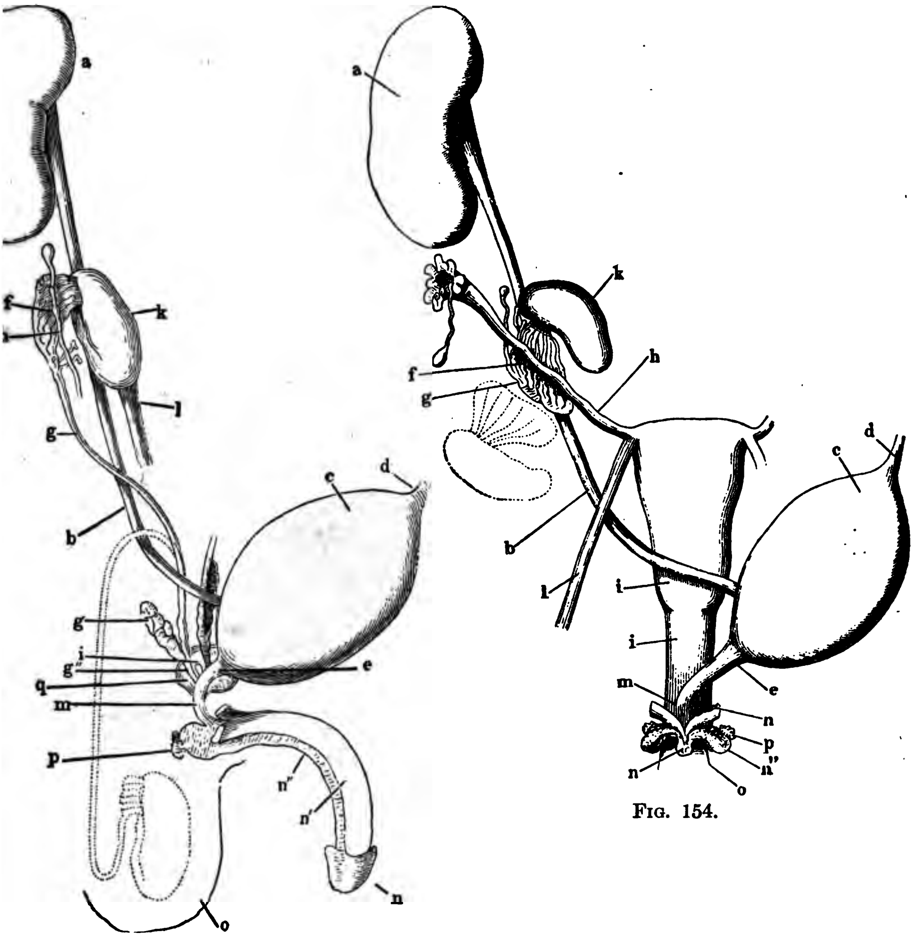


FIG. 153.

FIG. 154.

FIGS. 153 and 154. — Schematic drawings of the male and female reproductive organs, showing the correspondences and differences between them. *a*, kidney; *b*, ureter; *c*, bladder; *e*, urethra; *g*, in the male deferent duct, in the female a rudimentary structure known as the duct of Gartner; *g'* and *g''*, seminal vesicles and ejaculatory ducts, respectively, found only in the male; *h*, in the female uterine tubes, in the male the horns (sometimes present) of a rudimentary structure known as the uterus masculinus; *i*, in the female uterus and vagina, in the male the uterus masculinus above referred to; *k*, in the male testis, in the female ovary; *m*, urogenital sinus; *n*, in the male penis, in the female clitoris; *o*, in the male scrotum, in the female labia majora. (Henle.)

initiates the second reflex, the center of which lies in the lumbar region of the spinal cord, and results in the contraction of the musculature of the seminal vesicles and urethra by which the semen (fluid containing spermatozoa) is forcibly ejected into the vagina of the female.

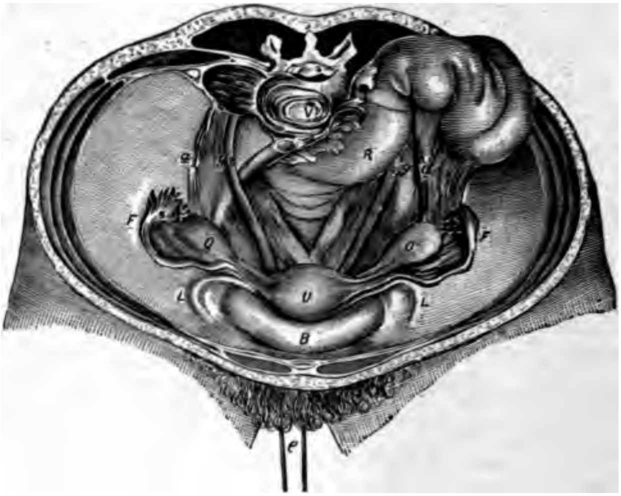


FIG. 155 *A*. — View of the pelvis and its organs in the female. *B*, bladder; *U*, uterus (drawn down by loop, *e*); *F*, uterine tubes; *O*, ovaries; *L*, round ligament; *g*, ureter; *a*, ovarian vessels; *R*, rectum; *V*, vertebræ. (Dorland.)

Once in the vagina the spermatozoa ascend, the direction opposed to that of the motion of the cilia of the uterus and uterine tubes. If one of them chances to meet an ovum in its descent from the ovary, fertilization takes place.

The number and variety of the structures involved in the act of fertilization and especially its dependence upon the condition of the cerebral cortex render the process especially liable to derangement and disease. The process is so fundamental that it is in large part reflex, and yet it requires the cortex not only for its control but also for its initiation. It is significant that the cortex is that part of the nervous system most susceptible to the effects of environment, be it good or bad, and that upon this effect must depend the proper disposition of the semen, and the subsequent history of the race.

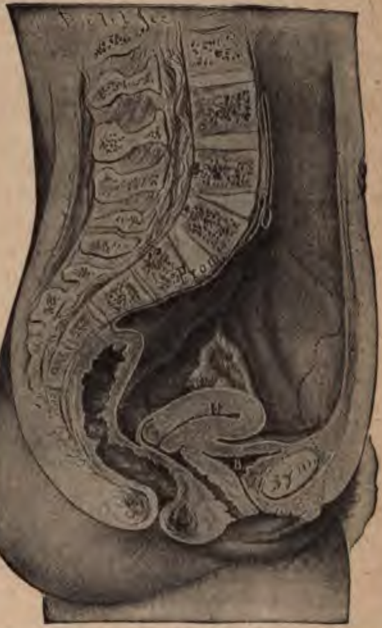


FIG. 155 *B*. — Female pelvic organs seen in sagittal section through the lower part of the trunk. *Prom*, promontory; *B*, bladder; *Sym*, symphysis pubis; *U*, uterus. (Kelly.) (Copyright by D. Appleton and Company.)

The Ovaries, Ovulation, Menstruation. — Sexual maturity is attained in the female at about the fourteenth year. It apparently depends for its occurrence upon an internal secretion of the ovary and may therefore be compared with the analogous condition already described as occurring in the male. The arrival of puberty is attested by the phenomenon of menstruation and various obvious external modifications of the physique. At this time ova begin to be extruded from the ovary at regular intervals and to pass down the uterine tubes into the uterus. The relation of this phenomenon (ovulation) to the other periodic phenomenon (menstruation) has not been established beyond question, but the following view has much in its favor. Under the influence of the internal secretion of the ovary, which seems to be especially active just before ovulation, the lining of the uterus becomes thickened and vascular. Ovulation then takes place, and if fertilization occurs, the ovum finds in the uterus an especially prepared environment suitable for its development. If the ovum is not fertilized, the modified lining of the uterus is needless, the newly formed tissues disintegrate and the hemorrhagic discharge constitutes the menstrual flow.

After the fertilization of the ovum, which usually occurs while the ovum is descending through one of the uterine tubes, the ovum begins to divide. It also continues its downward course, and on reaching the uterus it becomes fixed to the thickened wall of that organ.

Development of Fetus, Membranes, and Placenta. — The study of the changes which now occur constitute the science of embryology, into which unfortunately we cannot enter. Suffice it, with the aid of the accompanying diagrams, to outline the development of the fetal membranes and placenta and their relation to the embryo properly so called.

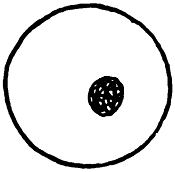


FIG. 156.— Diagram of ovum before segmentation.

Figure 156 shows the fertilized ovum ready to divide. In figure 157 the division into cells has begun and in figure 158 it is seen to have advanced considerably. In the subsequent diagrams the separate cells are not indicated. In figure 159 a part of the embryo is seen to have sunk below the general level of the surface, while the edges of the pit in which it lies are growing up over this part of the embryo. A later stage is seen in figure 160. Later the edges of the pit coalesce (Fig. 161) *so that* a closed cavity is formed (AC). This is filled

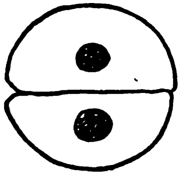


FIG. 157.—Diagram of ovum after segmentation has begun; two-cell stage.

with liquid and is called the amniotic cavity. It serves to protect the developing embryo from mechanical injury throughout the whole period of gestation.

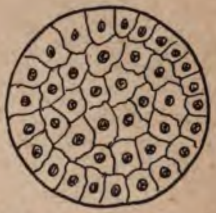


FIG. 158. — Diagram of ovum after a considerable amount of cell-division has taken place.

The portion which has been referred to as sinking down is that which ultimately becomes the embryo proper, while the remaining structures form the embryonic membranes, namely, the amnion (Fig. 160, *a*), which lines the amniotic cavity, and the chorion (*c*), which is the part in contact with the uterine wall.

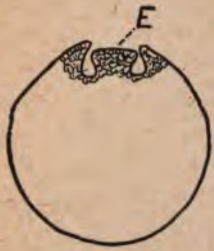


FIG. 159. — Diagram showing the beginning of development of embryo. Here the cellular structure is only partially indicated. *E*, embryo.

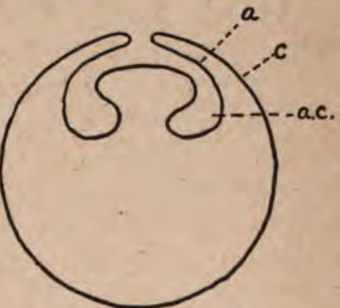


FIG. 160. — Diagram showing the approaching edges of the pit in which the embryo lies. *a*, amnion; *c*, chorion; *a.c*, amniotic cavity in process of formation.

As the amniotic cavity (Fig. 161, *AC*) enlarges the embryo comes to be connected with the chorion only by means of a stalk (the umbilical cord, *UC*). This stalk contains blood vessels, veins, and arteries (*BV*) which have grown out from the body of the embryo into the chorion. The latter sends down into the uterine wall processes (villi, *CV*), into which the blood vessels already referred to penetrate and come to lie in juxtaposition to the blood vessels of the mother, which become enormously increased. The union of these two

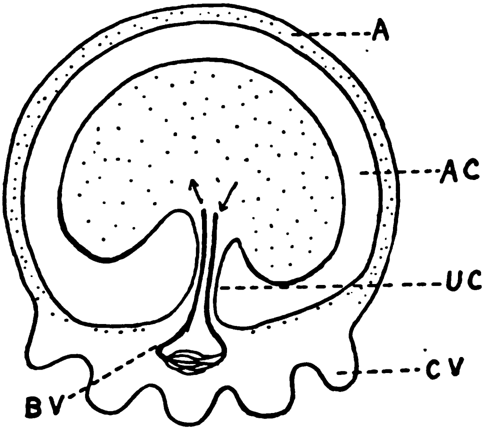


Fig. 161. — Diagram showing embryo, membranes, and placenta. Cellular structure not indicated. *A*, amnion; *AC*, amniotic cavity; *UC*, umbilical cord; *BV*, blood vessels, umbilical artery and vein, of embryo; *C.V.*, chorionic villi.

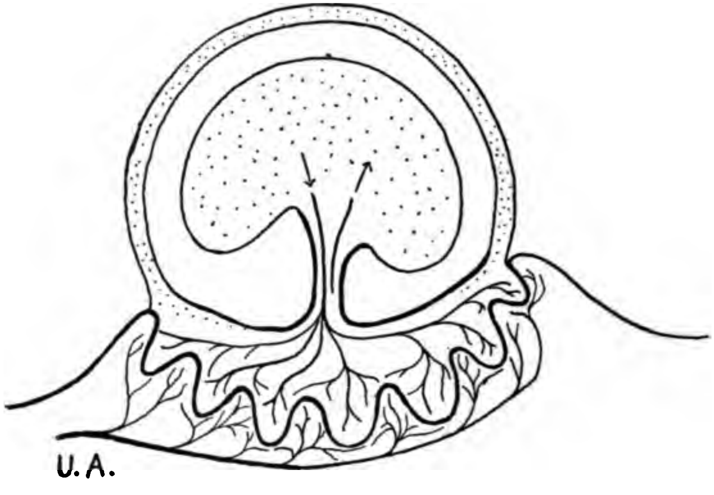


Fig. 162. — Diagram: relations in placenta. For the sake of simplicity only the arteries are represented. Structures as before, but umbilical artery is more extensively developed and the uterine artery (*UA*) is added. Cellular structure not represented.

structures, the chorion with its villi and vascular network and the part of the uterine wall which has become thickened and highly vascular, forms the placenta, which is consequently partly fetal and partly maternal in origin (Fig. 162).

Nutrition of Fetus. — The embryo has now established nutritive relations with the mother. Its nutrition is dependent upon the interchange of foodstuffs, oxygen, and waste products between the circulation of the mother and that of the fetus, where their capillaries come into juxta-

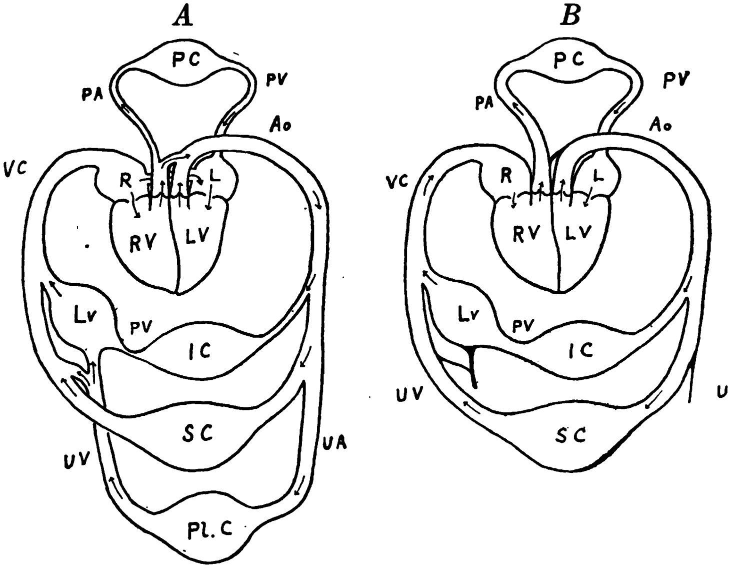


Fig. 163. — Diagrams showing the peculiarities of the fetal circulation. *A*, fetal circulation; *B*, adult circulation to be compared with *A*. The lettering is the same in both *A* and *B*. *R*, right atrium; *RV*, right ventricle; *PA*, pulmonary artery; *PC*, pulmonary capillaries; *PV*, pulmonary vein; *L*, left atrium; *LV*, left ventricle; *Ao*, aorta; *IC*, intestinal capillaries; *PV*, portal vein; *Lv*, liver; *VC*, vena cava; *SC*, systemic capillaries; *UA*, umbilical artery; *PlC*, placental capillaries; *UV*, umbilical vein. Note the following: in *A*, pulmonary and intestinal circulations feeble, inter-atrial septum perforated, connection between *PA* and *Ao*, placental circulation present, PV unimportant; in *B*, *R* and *L* are quite separate, the connections between the P A and *Ao* and the umbilical vessels are rudimentary.

position in the placenta. Consequently foodstuffs are not brought to the fetus from its own intestine by means of the portal circulation but from the placenta by the umbilical vein; the CO_2 produced by the fetus is not carried by the pulmonary artery to the fetal lungs but by the umbilical arteries to the placenta (Fig. 163). To the embryo the placenta is both lungs and intestine and the maternal blood is both air and food. As is the case with the portal circulation in later life, the blood from the placenta passes to the liver and thence to the heart. The passage of the blood through the heart is so modified that most of it never reaches the lungs at all. For of that which enters the right auricle part passes directly through an opening in the interatrial septum (foramen ovale) to the left atrium and thence to the aorta, while of that which enters the pulmonary artery part passes directly into the aorta through the short ductus arteriosus which connects the pulmonary artery directly with the aorta. During pregnancy various changes occur in the mother. The uterus increases in size from 35 grams to 1000 grams, a reaction, it appears, to some chemical stimulus of the growing fetus. As might be expected, the nitrogenous equilibrium of the mother is disturbed, *i.e.* more nitrogen is ingested than is excreted. Throughout this period also the mammary glands show active enlargement. This is probably due to some chemical stimulus (hormone) produced by the fetus.

Parturition. — It is not improbable that it is owing to an internal secretion of the mammary glands that labor is subsequently brought about. But whatever its cause a time at length arrives (about nine months after fertilization) when the uterus begins to contract and with the assistance of the abdominal muscles (see p. 154) expels the fetus. A little later the placenta, including both the maternal and fetal part and the fetal membranes, is expelled from the uterus, leaving behind a raw surface which is prevented from bleeding profusely by the strong contractions of the uterus, which compress the blood vessels of the organ until clotting of the blood has plugged their open ends.

Since the new-born infant can no longer utilize the blood of the mother as a respiratory medium, its own blood becomes venous in character. This condition of the blood is, as has been seen, the normal stimulus of the respiratory center. The irritability of the center is also raised by the inrush to it (as to all the other centers) of a host of new sensory stimuli from all parts of the skin. Thus the automatic action of the respiratory center begins, but

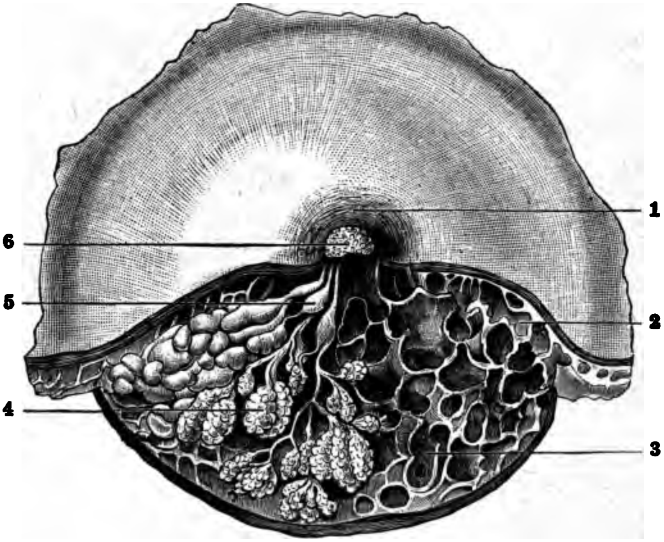


FIG. 164. — The female mamma during lactation. 1, areola; 2, cavity whence the fat has been dissected out; 3, cavity whence glandular tissue has been removed; 4, acini of gland; 5, dilated part of gland duct; 6, mammilla. (Luschka.)

from the start is assisted and modified by reflexes from the sensory nerves.

Lactation. — This completes the process of reproduction, except in so far as lactation is concerned. For after birth the infant continues to derive nutriment from the mother, no longer by a transfer from the circulation of the latter to that of the former, but in a more indirect manner, namely by ingestion on the part of the infant of the external secretion of the mammary glands of the mother or of some substitute such as a foster mother or a cow.

The mammary glands are specialized skin glands closely akin to the sebaceous glands (Fig. 164). It is thought that the hormone which causes their growth also inhibits this secretion. With parturition the source of this substance is withdrawn and the gland ceases to grow, but begins to secrete.

APPENDIX

THE PLOTTING OF CURVES

THE plotting of curves is a subject with which every nurse should be familiar. The principle is simple and can best be demonstrated by means of the following examples.

(1) Suppose one were asked to make a curve showing the total amount of urine voided per day by a patient in the ward.

The nurse's report book shows the following figures for the last six days:

1st	day,	1800 c.cm.
2d	day,	2800 c.cm.
3d	day,	1800 c.cm.
4th	day,	2500 c.cm.
5th	day,	700 c.cm.
6th	day,	900 c.cm.

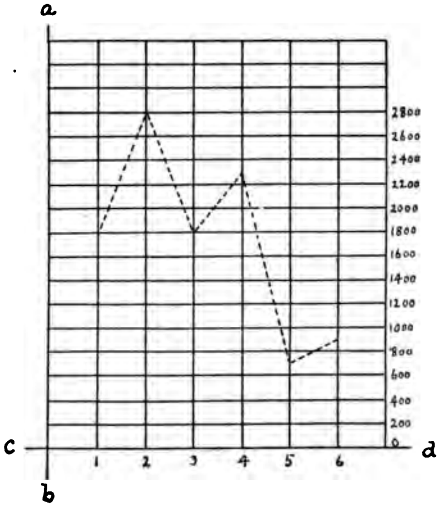


FIG. 165. — Urine chart. Curve of daily excretion of urine.

We draw two lines at right angles, one vertical (*ab*), one horizontal (*cd*). Then we divide (*ab*) and (*cd*) into a number of equal parts and let each of the vertical divisions represent say 200 c.cm. of urine and each of the horizontal divisions represent one day (Fig. 165).

The first point on the curve is one to the right of the vertical line and nine above the horizontal line, and the second is two to the right and fourteen above and so forth.

(2) If we were to keep a temperature chart we would proceed in precisely the same way (Fig. 166).

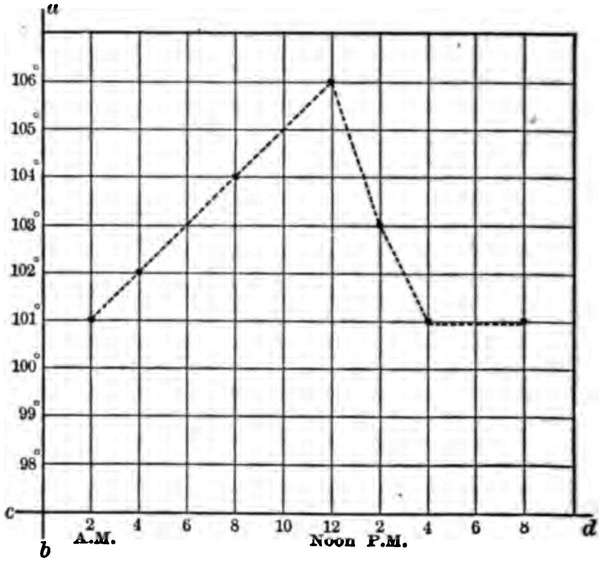


FIG. 166. — Temperature chart.

Suppose the record in the nurse's temperature book is:

2 A.M.	101° F.
4 A.M.	102° F.
8 A.M.	104° F.
12 noon	106° F.
2 P.M.	103° F.
4 P.M.	101° F.
8 P.M.	101° F.

The curve corresponding to these figures would be made in the same way.

(3) In many hospitals and in some other public buildings it is thought advisable to keep a continuous chart of the temperature in the wards or rooms. This is easily done by means of a self-registering thermometer in which, as a rule, changes of temperature affect a spring, which in turn moves a lever. The lever of such a thermometer is connected with a pen in such a manner that, as the temperature rises, the pen rises and as the temperature falls, the pen falls.

All that is necessary then is to have a sheet of paper moved along at an even rate beneath the pen, which as it moves vertically (or describes a slight arc) writes on the paper as the latter moves horizontally. In this way the thermometer draws its own temperature curve (Fig. 167).

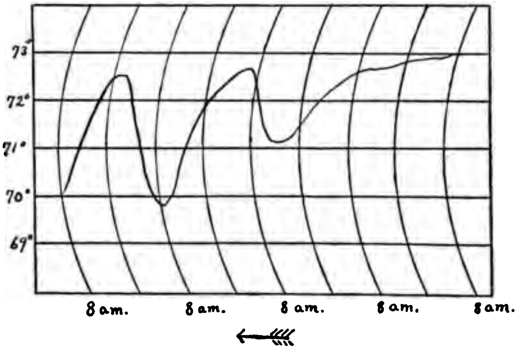


FIG. 167. — Chart made by a self-recording thermometer. Note that the ordinates are curved. This is because the writing point was affixed to a lever which was pivoted to the right of the writing point. The arrow indicates the direction in which the paper was moved, and consequently the curve is to be read from left to right.

(4) Next suppose we wish to study the way in which a muscle contracts. We attach the muscle to some sort of device such as a lever, which will record the movement of the muscle, just as, in the case of the self-recording thermometer, we had a device for recording the movement

of the mercury (or spring). Thus the contracting muscle draws a line on a sheet of paper which is moving at a known rate and the curve is obtained (Fig. 30).

From these examples of curves, it may be seen that they may serve one or both of the following uses. In the case of the urine curve and the curve of the patient's temperature, the object is to present to the eye in a clear and concise way facts which are already known, while in the case of the automatic temperature recorder and the muscle, the object in view is to obtain an exact record of events which we would not or could not observe directly, either on account of the long duration of the changes (temp.), or on account of their extreme rapidity (muscle).

INDEX

5 = page 5
(5) = Fig. 5

Abducens nerve, 52
Absorption, 220
Accommodation, 130–132, (95), (96)
Acetabulum, 78
Acid,
  Hydrochloric, 215
  Lactic, 38, 45, 95
Acoustic meatus,
  External, (99)
  Internal, 54, 57
Acoustic nerve, 57
Acquired reflexes, 107
Action — kinds of nervous,
  Automatic, 86
  Reflex, 87, (69)
Activators, 211
Agnosia, 113
Agraphia, 115, (84)
Alar ligament, left, (49)
Amœba, 8, 85
Anterior atlanto-epistrophic ligament, (49)
Anterior atlanto-occipital ligament, (49)
Antibody, 194
Antigen, 194
Aorta, 147, (102)
Aphasia, 115, (84)
Aphemia, 115, (84)
Apical dental ligament, (49)
Arc — Reflex, 90, (71)
Arrangement of the neurones, 97
Arteries,
  Elasticity of, 156
  Extensibility of, 156
  Nervous control of, 118, 162, (114–118)
Arteries, List of,
  Internal carotid, 59
  Meningeal, 54
  Middle meningeal, 57
  Vertebral, 55, 59
Atoms, 5
Auditory tube, 57
Axones, 86, (67), 96, 99, (77)
Biceps muscle, 68, 70, (55), 72
Bile, 232
Bladder, 237
  Function of, 237
  Nerve supply of, 237
  Tonus of, 237, (151)
Blind spot, 135
Blood,
  Clotting of, 198
  Composition of, 191, 194
  Diffusion of, 192
  Explanation of velocity of, 167
  Hemolysis of, 191
  Leucocytes of, 197
  Lymph, 200, (132)
  Origin of red blood corpuscles, 197
  Osmotic pressure of, 192
  Velocity of, 167
Blood pressure,
  Determination of, in man, 161
  Explanation of, 157
  Relation of, to heart rate and strength of heart beat, 161
  Relation of, to resistance, 161
Bone — Development of, 26, (15 A)
Bones, List of,
  Calcaneus, 84
  Carpal, 72
  Clavicle, 52, 67
  Concha, 51
  Coccyx, 61
  Ethmoid, 49, 51, 52
  Femur, 78
  Fibula, 83
  Frontal, 49
  Humerus, 71
  Hyoid, 59
  Ilium, 72
  Ischium, 72
  Lachrymal, 49
  Mandible, 52
  Maxillary, 50
  Metacarpals, 72
  Nasal, 55
  Occipital, 54

- Bones, List of — *continued*
  - Parietal, 54
  - Phalanges, 72
  - Pubis, 72
  - Radius, 72
  - Ribs, 66, (51)
  - Sacrum, 73
  - Scapula, 67
  - Sphenoid, 52
  - Sternum, 52
  - Temporal, 52
  - Tibia, 83
  - Ulna, 72
  - Vertebræ, 53 (*see also* Vertebræ)
  - Vomer, 55
  - Zygomatic, 52
- Brachial plexus, 103
- Brain, parts of,
  - Cerebellum, 101
  - Cerebral cortex, 109
  - Cerebrum, 101
  - Medulla, 93, 106
- Bronchi, 37
- Buccinator muscle, 55, (42)

- Calcaneus, 84
- Calf muscles, 84
- Calorie, 247, 248
- Capillaries, 167
- Capsular ligament, 64, (49)
- Carbohydrates,
  - Balance of, 245
  - Fate of, in body, 245
  - Function of, 246
- Carbon dioxide, 45
- Cardio-accelerator center, 93
- Cardio-inhibitory center, 90
- Carotid canal, 57
- Carpal bones, 72
- Cartilage,
  - Costal, 66, (51)
- Cell doctrine, 15
- Cells,
  - Connective tissue, 21
  - Development of, 15
  - Differentiation of, 14
  - Epithelial, 18
  - Leucocytic, 17
  - Nerve — (neurone), 85, (67)
- Centers of,
  - Coördination, 93
  - Ossification, 26, (15 B)
  - Reflex action, 93
- *Cerebellum*, 101, 116
- *Cerebral* cortex, 109, 110
- Cerebral localization, 113
- Cerebrum, 101
- Cilia, 36, (24)
- Circulation, 144, 145, (101)
  - List of topics under,
  - Apex impulse, 150
  - As a whole, 145
  - Arteries, 156
  - Capillaries, 167
  - Determination of blood pressure, 161
  - Diastole of heart, 160, 161
  - Explanation of velocity, 167
  - Function of, 146
  - Heart beat, 151
  - Heart sounds, 150
  - Nervous control of arteries, 162
  - Pulse, 170
  - Systole of heart, 160, 161
  - Veins, 170
  - Wave of contraction, 149
- Clavicle, 67, 52
- Clotting,
  - Constituents present in, 198
  - Process of, 198
  - Time element in, 199
- Coccyx, 61
- Color, 134
- Compounds — Chemical, 5
- Conduction, 85
- Concha, 51
- Connective tissues, List of,
  - Areolar, 22
  - Bone, 21, 23, (11), (12), (13)
  - Cartilage, 21, 23, (10)
  - White fibrous, 21, 22, (7), (8)
  - Yellow elastic, 21, 23
- Conservation of energy, 1
  - Of matter, 1
- Contractile tissue, properties of, 36
- Contractility, 36
- Contraction, 41, 42, (33), (35), (36), (31), (37), 43
- Coracoid process, 68
- Cortical connections, 117, (85)
- Costal cartilage, 66, (51)
- Cranial autonomic nerves, 107
- Crucial ligament, 64, (49)
- Curves, plotting of, 267, (165), (166), (167)
- Cytoplasm, 8, 22, (9), 85, (67)

- Decomposition in small intestine, 228
- Defecation,
  - Factors influencing, 208, (136)
  - Process of, 208, (136)

Deferent duct, 37
Degeneration of nerve fibers, 96
Deltoid muscle, 63, (48), 71
Dendrites, 86, (67)
Density of gases, 177
Descent, doctrine of common, 16
Diaphragm muscle, 66, 67, (52), (53)
Diaphysis, 29
Diastase, action of, 224
Diastole, 161
Digestion,
  In complex organisms, 203
  In large intestines, 231
  In small intestines, 227
  In unicellular organisms, 203
  Process of, 204

Ear, function of, 138
Ear, parts of,
  Acoustic canal of, 138
  Cochlea of, 139
  Endolymph, 140
  Eustachian tube of, 138
  Fenestra cochleæ of, 138
  Fenestra vestibuli of, 138
  Ossicles of, 138
  Pinna of, 138
  Scala tympani, 139
  Scala vestibuli, 139
  Semicircular canals of, 138
  Vestibule of, 138
Elements — Chemical, 4
Embryo, 260, (159–162)
Endothelium, 19
Energy,
  Conservation of, 1
  Kinetic, 3
  Mechanical, 37
  Muscular, 37
  Of position, 2
  Photic, 3
  Potential, 3
  Source of, 37
Enzymes,
  Action of, 209
  Properties of, 210
Epicritic nerve fibers, 120
Epididymus, 37
Epiphyses, 29, (15 B)
Epithelium,
  Ciliated, 19, (6)
  Columnar, 18
  Neuro-, 19
  Retinal, 133
  Squamous, 18, (4)
Epithelium — *continued*
  Stratified squamous, 18
Equations — Chemical, 6
Ergogram, 46, (36)
Ethmoid bone, 49, 51
Eustachian tubes, 37, 138
Excitation, 40, (26), 89, 91, 94
Extensors of leg, (62)
External intercostal muscles, 65, (50)
External oblique muscle (48), (50), 67
Eye muscles, 137, (98)
Eye, 129
  Parts of,
  Blind spot, 135
  Fovea, 135
  Muscles, 137, (98)
  Pupil, 133
  Retina, 133

Facial nerve, 57
Fallopian tubes, 37
Fatigue, 43, (35), 44
  Curve of, 44
  Level, 46
  Substances, 45
Fats,
  Digestion of, 226
  Fate of, in body, 246
  Function of, 246
Femur, 78
Fertilization, 256, (153)
  Nervous mechanism of, 256
  Process of, 256
Fetus, 260
  Development of, 260
  Nutrition of, 263, (163)
Fibrinogen,
  Formation of, in liver, 235
  Function of, 198
Fibula, 83
Fissure,
  Infra-orbital, 52
Fontanelles, 59, (45)
Food,
  Energy of, in relation to body temperature, 247
Foodstuffs, 209
Foot, 83
Foramen,
  Infra-orbital, 51
  Intervertebral, 62
  Ischiadic, *see* Sciatic, 74
  Jugular, 59
  Magnum, 59
  Optic, 52

Foramen — *continued*
  Ovale, 57
  Sciatic, 74
  Spinosum, 57
  Stylo-mastoid, 57
  Supra-orbital, 50
Formulæ, chemical, 6
Fossa,
  Anterior cranial, 57, (43 B)
  Middle cranial, 57, (43 B)
  Posterior cranial, 59, (43 B)
Fovea, 135
Frontal,
  Bone, 49, 50, (39)
  Sinus, 54, (41)

Ganglion, 98
  Autonomic, 101, (79)
  Dorsal root, 97, (75)
  Semilunar, 57, 125
  Superior cervical, 107, (81)
  Vertebral, 107, (81)
Gases, 177
Gastric juice,
  Action of, 218
  Composition of, 215
  Methods of studying, 216
  Nervous control of, 217
  Secretion of, 215
Gastric movements, 205
Gastrocnemius, 80, 82, (65), 84
Glands, 211, (137)
  Functional activity of, 212
  Mammary, 266, (164)
Glenoid cavity, 68
Gluteus medius muscle, 78
Glycogen, 37, 234
  Storage of, 234

Hand, 72
Heart,
  As a pump, 146, (101)
  Nervous control of, (154)
  Parts of, 145, (101), 149, (103), (104)
  Pericardium of, 151, (105)
Heart beat,
  Automaticity of, 153
  Cause of, 151
  Effect of heat upon, 152
  Factors affecting, 152
  Refractory period of, 153
Heat, 249
  Regulation of, 249
  Source of, in body, 249
Heat — *continued*
  Loss of, regulation in body of, 25
  Methods of losing, 251
Hemoglobin,
  Condition of, 196
  Function of, 196
  Properties of, 195
Hemolysis of red corpuscles, 191
Hormones, 35, 224
Hydrochloric acid, 215
Hypermetropia, 131

Iliacus muscle, 78, 81, (62–63)
Immunity,
  Explanation of, 195
  Phenomena of, 194
  Procedure of, 194
Infra-orbital foramen, 51
Inguinal ligament, 63, 76, (48)
Inhibition, 40, (26), 89, 94
Internal carotid artery, 59
Internal jugular vein, 55
Internal oblique muscle, 65, (50), 57
Internal secretion, 239
  Definition of, 239
  Of liver, 239
  Of ovaries, 240
  Of pancreas, 241
  Of parathyroids, 241
  Of suprarenal bodies, 239
  Of testes, 240
  Of thyroid gland, 241
Intervertebral foramen, 62
Intestine,
  Antistalsis in, 207
  Movement of, 206
  Nerve supply of, 207
Intestinal secretions, action of, 227
Ischiadic,
  Great, foramen, 74
  Great, nerve, *see* Great sciatic ner
    74

Jugular foramen, 59
  Vein, 56

Kidney,
  Circulation in, 236, (150)
  Function of, 235
  Secretion of, 236
Knee-jerk, 96

Lachrymal bone, 49
Lachrymal duct, 37
Lactation, 266

Lactic acid, 38, 45, 95
Large intestine,
  Absorption in, 231
  Decomposition in, 231
  Digestion in, 231
Larynx, 37
Latent period, 47
Latissimus dorsi muscle, 63, (48), (54), (55), 71
Law,
  Of conservation of energy, 4
  Of conservation of matter, 1
  Of Henry, 186
Leucocytes, 197
  Function of, 197
  Movement of, 197
  Phagocytic power of, 198
Ligament, 22
  Anterior atlanto-occipital, 64, (49)
  Anterior atlanto-epistrophic, 64, (49)
  Apical dental, 64, (49)
  Capsular, 64, (49)
  Crucial, 64, (49)
  Inguinal, 63, (48), 76
  Left alar, 64, (49)
  Patellar, 83
  Pelvic, 77, (61 A), 79, (61 B)
  Posterior atlanto-epistrophic, 64, (49)
  Suspensory, 132
  Transverse, 64, (49)
Ligaments of pelvis, 77, (61 A), 79, (61 B)
Ligamentum flavum, 64, (49)
  Nuchæ, 53
Lipase, action of, 224
Liver,
  Blood supply of, 232
  Function of, 232, 235
  Secretion of, 232
Load, effect of, 43
Localization,
  Cerebral, 113
  Of pain, 122
Lumbo-sacral plexus, 103
Lungs, 174
  Mechanism of, 174, 175, (124)
  Relation of lungs to atmospheric pressure, 180, (127)
Lymph, 200
  Circulation of, 201, (132)

Mammary glands, 266, (164)
Mandible, 52
Manometer, 157
  Explanation of, 158, 161, 162, (111)
Masseter muscle, 52
Mastication, 204
Mastoid,
  Cells, 138
  Notch, 57
  Process, 52
Matter, conservation of, 1
Maxillary bone, 50
Medulla, 93, 106
Meningeal artery, 54
Menstruation, 259
Mesothelium, 19
Metabolism,
  General consideration of, 242
  Of nervous system, 95
Metacarpal bones, 72
Micturition, 237
  Nervous control of, 237
Mixtures, 5
Molecules, 5
Motor nerves, *see* Motor neurone, 86, (68)
  Paralysis, 97, 115
Muscle, kinds of, 37
  Cardiac, 40, (29), 48
  Plain, 40, (28), 47
  Striated, 40, (27), 41
  Sphincters, 89
Muscles, List of,
  Adductors of thigh, 80
  Biceps, 68, 70, (55)
  Buccinator, 55, (42)
  Calf, 84
  Ciliary, 133, (96)
  Deltoid, 63, (48), 67
  Diaphragm, 66, 67, (52–53)
  Extensors of leg, (62)
  External intercostals, 65, (50)
  External oblique, (48), 67
  Gastrocnemius, 80, 84, (65)
  Gluteal, 80, (65)
  Gluteus maximus, 68, (54), 80
  Gluteus medius, 78
  Iliacus, 78
  Internal oblique, 65, (50), 67
  Latissimus dorsi, 63, (48), 65, (50)
  Masseter, 52
  Pectoralis major, 63, (48), 67, 70, (55)
  Psoas major, 64, 81, (62)
  Quadriceps femoris, 81, (62), 82, (65)
  Rectus abdominis, 65, (50)

Muscles, List of — *continued*
  Serratus anterior, 63, (48)
  Soleus, 82, (65), 84
  Sterno-cleido-mastoid, 52, 63, (48)
  Temporal, 55, (42)
  Tibialis posterior, 84
  Tibialis anterior, 84
  Transversus, 65, (50), 67
  Trapezius, 53, 63, (48)
  Triceps, 68, (54), 70, (55), (56), 72
Muscle sense, 123
Muscular tissue, 29
Myogram, 47, (37)
Myopia, 130

Nasal bone, 55
Nerve fibers, kinds of,
  Cardiomotor, 107
  Epicritic, 120
  Pilomotor, 107
  Protopathic, 120
  Vasomotor, 107
  Visceromotor, 107
Nerve impulse, 94
Nerve patterns, 91
Nerve trunk, 99, (77)
Nerves, List of,
  Abducens, 104, 52
  Accessory, 56, 106
  Acoustic, 57, 104
  Cranial autonomic, 107
  Cranial somatic, 103
  Facial, 57, 104
  Glossopharyngeal, 56, 104
  Hypoglossal, 106
  Oculomotor, 52, 104
  Olfactory, 103
  Optic, 103
  Sciatic, 74, 103, (80 B)
  Spinal autonomic, 106, (81)
  Spinal somatic, 102
  Trigeminal, 50, 57, 104
  Trochlear, 104
  Ulnar, 71
  Vagus, 55, 104
Nervous tissue, 29
Neurone, kinds of,
  Excitatory, 89, (70)
  Inhibitory, 89, (70)
  Motor, 87, (69), 88, 98
  Post-ganglionic, 107
  Sensory, 87, (69), 98
Nucleus, 95, 96
  Red, 117
Nutrition, equilibrium of, 242

Occipital bone, 54
Oculomotor nerve, 52
Opsonins, 197
Optic chiasma, 57
Optic foramen, 52
Optic nerve, 52
Optics, 127
Organisms, kinds of,
  Multicellular, 14
  Unicellular, 13, 85, 96
Os coxæ, 72, (57)
Osmosis, 192
Osteoblasts, 26
Osteoclasts, 29
Ovaries,
  Function of, 240
  Internal secretion of, 259
  Relation of, to menstruation, 259
Ovulation, 259
Ovum, 260
  Development of, 260
  Implantation of, 261, (156), (157)
Oxygen, 4, 5, 95, 183, 196

Pain, 122
Pancreas, 241
Pancreatic secretion, 221
Paralysis, kinds of, 97
  Motor, 97, 115
  Sensory, 97, 115
Parathyroids, 241
Parietal bone, 52
Parturition, 264
Patella, 83
Patellar ligament, 83
Pectoralis major muscle, 63, (48), 67, 70, (55), 71
Pelvis, 72, 73, (57–59), (61), (60), (63)
Pepsin, 217
  Action of, 217, 218
Perineurium, 99, (77)
Periosteal buds, 28
Periosteum, 24
Peristalsis, 205, (134)
Phalanges, 72
Placenta, 260
  Function of, 261, (162)
Plexus, 103
  Brachial, 103
  Lumbo-sacral, 103
Posterior atlanto-epistrophic ligament, 64, (49)
Pressure, of the blood, 157
  Of gases, 177
  Sense of, 121, (86)

Protein,
  Digestion of, 225, (144)
  Function of, 244
  Sparers, 244
Protopathic nerve fibers, 120
Protoplasm,
  Conductivity of, 9
  Irritability of, 9, 12, 45
  Motility of, 8, (1)
  Nutrition of, 11
  Properties of, 8, 11
  Reproduction of, 11
Pseudopodia, 8
Ptyalin,
  Action of, 214
  Effect of temperature upon, 214
Pulse,
  Dicrotic elevation in, 171, (122)
  Venous, 172
  Wave of dilatation of, 170
Punctiform distribution of sensory endings in the skin, 124
Pupil, 133

Quadriceps-extensor muscle, 83

Radius bone, 72
Reciprocal innervation, 91, (73)
Rectus abdominis muscle, 65, (50), 67, 76
Red blood corpuscles, 197
Referred pains, 122
Reflex,
  Acquired, 107
  Extensor, 94
  Patellar, 96
Reflex arc, 90, (71)
Reflex center, 93
  Cardio-accelerator, 93
  Cardio-inhibitory, 90
  Respiratory, 93
  Vaso-constrictor, 93
Regeneration, 96
Relaxation, 42, 91, (73)
Rennin, 217
  Action of, 217, 220
Reproduction, topics under,
  Fertilization, 255
  In unicellular organisms, 254
  Lactation, 266
  Menstruation, 259
  Multicellular organisms, 254
  Nutrition of fetus, 263, (163)
  Ovulation, 259
  Parturition, 264
Reproduction, topics under — *continued*
  Relation of ovaries to menstruation, 259
  Spermatozoa, 254, (152)
  Testes, 255
Respiratory center, 93
Respiration,
  Apnea, 189
  Aspiratory action of, on blood flow, 181
  Bronchial constrictor fibers, 190
  Cause and control of, 188
  Center of, 188
  Chemical composition of air, 185
  Dyspnea, 189
  Effect of, on body temperature, 184
  Effect of, on blood pressure and heart rate, 189
  Effect of stimulation on, 189
  Expiration, 182
  Fate of inspired air, 187
  Impure air results, 184
  Inspiration, 182
  Law of Henry, 186
  Mechanics of, 179
  Mechanics of pulmonary respiration, 185
  Muscular mechanism of, 182
  Nervous mechanism, 188, (128)
  Pressure, volume, and density of gases, 177
  Pulmonary, 185
  Relation of atmospheric pressure, 178, (126)
  Relation of the gases to the blood, 186
  Respiratory movements, 188
  Rôle of ribs, 183
  Uses, 174
  Volume of gaseous exchange, 183
Retina, 133
Ribs, 66, (51)

Sacrum, 73, (38), (58)
Salts, 246
  Function of, 246
  Osmotic relation of, 139
Scapula, 67, 68
Sciatic foramen, great, 74
Sciatic nerve, 74, 103, (80 B)
Secretion,
  Nervous mechanism of, 213
  Of bile, 232
  Of sweat, 238
  Pancreatic, 241

Secretion — *continued*
  Salivary, 214
  Suprarenal, 239
Semicircular canals, 138, 141, (99), (100)
  Action of, 142
Semilunar ganglion, 57
Senses, List of,
  Muscle sense, 123
  Pain sense, 122
  Sight, 127
  Smell, 126
  Solidity, 135
  Taste, 125
  Touch, 120
Sensibility, kinds of, 120
  Cutaneous, 120
  Subcutaneous, 120
  Visceral, 120
Sensory nerves, 88, (69), 87
  Paralysis, 97, 115
Septum,
  Cardiac, 149, (104)
  Nasal, 51
Serratus anterior muscle, 63, (48), 68
Sinuses, List of,
  Frontal, 54, (41)
  Mastoid, *see* Mastoid cells, 138
  Maxillary, 51
  Sphenoidal, 54, (41)
Skeleton, 49, (38)
Skull, 49, (39–42 B)
Small intestine,
  Absorption in, 227
  Decomposition in, 228
Smell, 126
Soleus muscle, 84, 82, (65)
Specific nerve energy, 90
Sphenoid bone, 52
Sphincters, list of,
  Of anus, 89
  Of bladder, 89, 237
  Of pupil, 89, 133, (96)
Spinal autonomic nerves, 106, (81)
Spinal cord, 97, (75), 101, 105, (80 C)
Spinal somatic nerves, 102
Spleen, function of, 235
Spontaneous generation, 12
Stability, 6
Sterno-cleido-mastoid muscle, 52
Sternum, 52
Stimuli, kinds of,
  Chemical, 12, 88
  Electric, 12
  Mechanical, 12
  Thermal, 12
Stomach, 220, (142 A)
  Arteries of, 220, (142 A)
  Coats of, 222, (142 B)
Stylo-mastoid foramen, 57
Supra-orbital foramen, 50
Suprarenal bodies,
  Function of, 239
  Secretion of, 239
  Secretory fibers of, 239
Sutures,
  Lambdoid, 53
  Sagittal, 53
Swallowing, 205
Sweat,
  Composition of, 238
  Secretion of, 238
  Secretory fibers of, 238
Symbols, chemical, 6
Symphysis pubis, 73
Synapse, 94, 98
Systems, List of,
  Autonomic nervous, 101
  Central nervous, 101
  Circulatory, 34, (22)
  Excretory, 32, (16)
  Nervous, 35, (23)
  Respiratory, 32, (16–23)
  Secretory, 30, 31, (20, 21)
Systole, 161

Tactile discrimination, 124
Taste, 124
Temporal muscle, 55, (42)
Temporal bone, 52
Tendons, 22
Tendon of Achilles, 84
Testes, function of, 240
Thorax, aspiratory action of, 181
Thyroid gland, 241
Tibia, 83
Tibialis muscle, 84
Tibialis anterior muscle, 84
Tigroid bodies, 85, (67), 95, (74)
Tonus, 38, (25), 88
  Central, 39, 153
  Muscular, 39
  Nervous, 39
  Peripheral, 38, 47, 153
Trachea, 37
Transverse ligament, 64, (49)
Transversus muscle, 65, (50), 67
Trapezius muscle, 53
Triceps muscle, 68, 70, (55), 72, (56)
Trigeminal nerve, 50

Trypsin, 224
  Action of, 224

Ulna, 72
Ulnar nerve, 71
Urea, formation of, in liver, 235
Ureters, 236
Urethra, 37, 237, (151)
Uterus, 37, 259, (154–155)

Vagina, 37, 259, (154–155)
Vas deferens, *see* Deferent duct, 37, (153)
Vaso-constrictor center, 93
Veins,
  Internal jugular, 56
  Valves of, 170
Vertebræ,
  Atlas, 61, (46)
  Axis, 61, (46)
  Cervical, 61, (46)
  Coccygeal, 61, (46)
  Epistropheus, 61, (46)
  Lumbar, 61, (46)
  Sacral, 61, (46)
  Thoracic, 61, (46)
Vertebral artery, 55
Vitamines, 246
Volume of gases, 177
  Of the heart, *see* Tonus, 153, (107)
Vomer (bone), 55

Zygomatic bone, 52

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Adjunct Pediatrist to Mt. Sinai Hospital; Director of the Pediatric Department of the New York Maternity Polyclinic and Director in the American Association for the Study and Prevention of Infant Mortality, etc.

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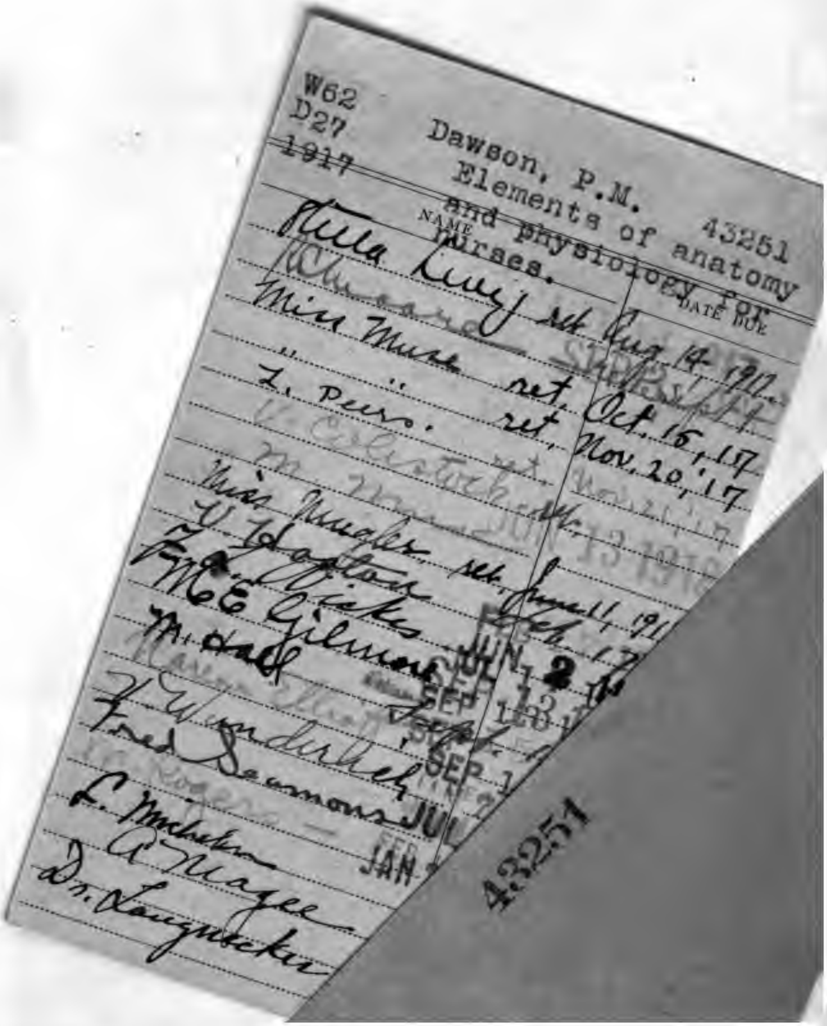

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